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## **NHTSA Light Vehicle Antilock Brake System Research Program Task 7.2:**

### **Examination of ABS-Related Driver Behavioral Adaptation – On-Road MicroDAS Study**

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16. Abstract  <p>Numerous crash data statistical analyses conducted over the past few years suggest that, for automobiles, the introduction of four-wheel antilock brake systems (ABS) has produced net safety benefits much lower than originally expected. The studies indicate that the apparent increase in single-vehicle crashes involving passenger cars equipped with four-wheel ABS almost completely offsets the safety advantage such vehicles have over their conventionally-braked counterparts. Other studies have suggested that this may be occurring due to behavioral adaptation because people drive faster in ABS-equipped vehicles. As part of its Light Vehicle ABS Research Program, NHTSA conducted an on-road instrumented vehicle experiment to investigate the possibility of behavioral adaptation resulting from ABS.</p> <p>An experiment was conducted to determine, in a real-world environment, whether people drive differently in vehicles equipped with antilock brake systems than they do in vehicles equipped with conventional brake systems. Six instrumented vehicles were provided to qualified subjects for 2-month periods (1 month with ABS and 1 month without) in order to gather naturalistic driving data with a minimum of experimental artifacts. A secondary goal of this study was to investigate whether any observable behavioral changes assumed to be a result of behavioral adaptation might vary as a function of driver age.</p> <p>The results of this study showed that the type of brake system (ABS or conventional) had no significant effect on any of the vehicle performance metrics examined in this study. These metrics included four types of speed evaluations, lateral and longitudinal accelerations, steering rate, mean and mean minimum time headway, and lane change and passing activity. In addition, no significant interaction effects were found when examining these metrics. However, significant effects due to driver age were found. These age effects were as expected but served as a valuable check on the validity of the methodology used.</p> <p>This NHTSA effort to assess behavioral adaptation under real-world conditions has produced data contrary to earlier test track studies. Drivers of ABS-equipped vehicles did not drive faster, exert higher brake pedal forces, or accelerate faster than their conventionally braked counterparts. This study does validate other recent NHTSA studies that found lack of observable differences in speed and brake pedal force. These results continue to suggest that the inclusion of ABS has no impact on the manner in which a vehicle is driven, especially under normal operating conditions.</p>					
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## EXECUTIVE SUMMARY

Numerous crash data statistical analyses conducted over the past few years suggest that, for automobiles, the introduction of four-wheel antilock brake systems (ABS) has produced net safety benefits much lower than originally expected. The studies indicate that the apparent increase in single-vehicle crashes involving passenger cars equipped with four-wheel ABS almost completely offsets the safety advantage such vehicles have over their conventionally-braked counterparts. Other studies have suggested that this may be occurring due to behavioral adaptation because people drive faster in ABS-equipped vehicles. In particular, one study showed that, on a closed course, subjects who received an explanation of the benefits of ABS and practice in an ABS-equipped vehicle, would drive faster, accelerate faster, wait longer before beginning their stop, and use higher brake pedal forces in vehicles with ABS than the control group that received no explanation and drove a conventionally braked vehicle. As part of its Light Vehicle ABS Research Program, NHTSA conducted an on-road instrumented vehicle experiment to investigate the possibility of behavioral adaptation resulting from ABS.

This experiment was conducted to determine, in a real-world environment, whether people drive differently in vehicles equipped with antilock brake systems than they do in vehicles equipped with conventional brake systems. Instrumented vehicles were provided to qualified subjects for two-month periods, one month with ABS and one month without, in order to gather naturalistic driving data with a minimum of experimental artifacts. Vehicle operating characteristics of interest included vehicle speed, applied steering wheel rate, applied brake pedal force, lateral acceleration during lane changes, number of lane changes completed, longitudinal acceleration, and frequency of ABS activation and crashes. A secondary goal of this study was to investigate whether any observable behavioral changes assumed to be a result of behavioral adaptation might vary as a function of driver age.

The results of this study showed that the type of brake system (ABS or conventional) had no significant effect on any of the vehicle performance metrics examined in this study. These metrics included four types of speed evaluations, lateral and longitudinal accelerations, steering rate, mean and mean minimum time headway, and lane change and passing activity. In addition, no significant interaction effects were found when examining these metrics. However, significant effects due to driver age (by itself) were found. These age effects were as expected but serve as a valuable check on the validity of this methodology.

This NHTSA effort to examine behavioral adaptation under real-world conditions has produced data contrary to earlier test track studies. Drivers of ABS-equipped vehicles did not drive faster, exert higher brake pedal forces, or accelerate faster than their conventionally braked counterparts. This study does validate other recent NHTSA studies that found lack of observable differences in speed and



brake pedal force. These results continue to suggest that the inclusion of ABS is not associated with added observable risk-taking behavior in average drivers.

## **1.0 INTRODUCTION**

### **1.1. Effects of ABS on Crash Rates**

Antilock brake systems (ABS) have been introduced on many passenger car and light truck make/models in recent years. In general, ABS appear to be very promising safety devices when evaluated on a test track. Under many pavement conditions, antilock brake systems allow the driver to stop a vehicle more rapidly while maintaining steering control even during situations of extreme, panic braking. Brake experts anticipated that the introduction of ABS on passenger vehicles would reduce both the number and severity of crashes. However, a number of crash data analyses have been performed in recent years by NHTSA, automotive manufacturers, and others that indicate that the introduction of ABS has not reduced the number of crashes where ABS were expected to be effective. Results of these analyses suggest that, for automobiles, the introduction of ABS has produced net safety benefits much lower than originally expected for ABS-equipped light vehicles [2,3,4,5]. Safety benefits due to ABS were seen in light truck (rear-wheel ABS only) crash data studies.

Kahane [1] found that, with the introduction of ABS, involvements in fatal multi-vehicle crashes on wet roads were significantly reduced by 24 percent, and nonfatal crashes by 14 percent. However, these reductions were offset by a statistically significant increase in the frequency of fatal single-vehicle, run-off-road crashes, as compared to cars without ABS. Fatal run-off-road crashes were up by 28 percent and nonfatal crashes by 19 percent.

A later, 1998 study by Hertz, Hilton, and Johnson [2,3] was similar to an earlier study by the same authors [4] except that it was based on more recent (1995 - 96) crash data. The effects found by the 1998 study were generally similar to the findings of the earlier study except that ABS now appears to be decreasing one particular subtype of single-vehicle road departure crashes, frontal impacts with fixed objects, rather than increasing their numbers.

Hertz et al [5], published in 2000, was the most recent NHTSA study of ABS-related crash data. This analysis differed from the earlier work by Hertz in that it included vehicles whose owners had selected ABS as an option. The inclusion of the vehicles with optional ABS did not seem to make very much difference in the estimation of the effect of all-wheel ABS in crashes of all severities. Results showed that ABS still seemed to have a beneficial effect in preventing each crash type except for side impacts, where it appeared to be associated with a higher crash rate, especially for passenger cars. However, it appeared to be beneficial in preventing pedestrian crashes, rollovers, run-off-road crashes, and frontal crashes with another moving vehicle. The previous Hertz study [6] indicated several instances where ABS was not beneficial in fatal crashes. The only statistically significant one remaining in the 2000 study [5] was rollovers of LTVs.

### **1.2. NHTSA's Light Vehicle ABS Research Program**

In an effort to investigate possible causes of the crash rate phenomena identified, NHTSA developed its Light Vehicle ABS Research Program. This program contained nine separate tasks that addressed potential theories as to the cause of the lack of net crash benefits associated with ABS. These potential contributing factors included driver behavior in a crash-imminent situation, driver response to ABS activation, ABS hardware performance, and environmental factors (as outlined in [7]).

Task 1 of NHTSA's Light Vehicle ABS Research Program, performed by Hertz in 2000 [5] as mentioned in the previous section, involved performing a new crash data study of the effect on safety of adding four-wheel ABS to automobiles. This study differed from those previously conducted [1,2,3,4] in that it focused on newer vehicles and antilock brake systems and also included some methodological improvements. This study endeavored to address whether whatever problem may have caused the apparent increase in single-vehicle crashes for ABS-equipped automobiles still existed following the introduction of newer generation ABS hardware.

Task 2 [9] of this program involved conducting a national telephone survey to determine drivers' knowledge and expectations about ABS. The purpose of this 1998 survey was to assess whether the apparent increase in single-vehicle crashes for automobiles might be due to drivers' misunderstanding of ABS functionality. Results of the survey showed that, although most drivers had heard of ABS, many did not know what it did or how it affected vehicle performance, when it functioned, or even if their vehicle was so equipped. Certain types of brake pedal feedback from an activated ABS were often misinterpreted, making driver reaction inappropriate and in some cases potentially dangerous. There was also some evidence drivers of ABS-equipped vehicles placed more confidence in ABS and what it could do for them than the non-ABS owners did. Lastly, this survey also found that information imparted at the time of purchase was the means by which the majority of drivers find out about the brakes on their vehicle. However, approval ratings for lengthy or mandatory information sessions were not well received, though some methods held promise.

Task 3 involved the examination of 257 selected single-vehicle 1996 crash reports collected by the National Automotive Sampling System (NASS). The goal of this work was to determine what differences could be identified in the characteristics of single-vehicle crashes incurred by ABS-equipped versus non-ABS-equipped automobiles using NASS Crashworthiness Data System (CDS) cases. Results of this examination of crash cases did not provide conclusive evidence that ABS had a significant effect on crash rates for the time period covered.

Task 4 [8] measured the braking performance of a group of model year 1993-97 production ABS-equipped vehicles over a broad range of surfaces and maneuvers. While ABS stopping performance has been measured by many groups over many years, there is a possibility that poor performance on some unusual surface or during some maneuver may have been overlooked. If such poor performance could be found, this might explain the apparent increase in single-vehicle crashes of ABS-equipped automobiles. The braking performance of nine high production passenger vehicles was evaluated in eighteen stopping situations. These situations were comprised of various road surfaces, driver steering actions, and vehicle speeds. Testing was performed with lightly and heavily laden vehicles, with the ABS active and disabled, and used two brake pedal application techniques. The selected vehicles included at least one ABS from each of the eight current, major, ABS manufacturers. This study found that for most stopping maneuvers on most surfaces, ABS-assisted full pedal brake application stops were shorter than those made with the ABS disabled. The one systematic exception was on loose gravel where stopping distances increased by an average of 27.2 percent overall. Additionally, the vehicular stability during testing was almost always superior with the assistance of ABS. For the cases in which instability was observed, ABS was not deemed responsible for its occurrence. Based on results to date, the authors of this study believe ABS braking performance deficiencies are not responsible for the apparent increase in ABS-equipped, single-vehicle, run-off-the-road crashes.

Task 5 examined the hypothesis that the apparent increase in single-vehicle crashes with ABS-equipped vehicles is due to driver “oversteering” in crash-imminent situations. In a crash imminent situation, a driver’s first action is expected to be a very hard application of the brake pedal. Oversteering occurs when the driver, possibly believing that the hard braking input is insufficient to avoid the upcoming obstacle (such as another vehicle), rapidly turns the steering wheel by a large amount. For conventionally braked or rear-wheel ABS only vehicles, this oversteering has little effect, since the initial driver brake pedal activation is likely to lock the vehicle’s front wheels. However, for a vehicle equipped with four-wheel ABS (where the ABS minimizes front wheel lockup and allows the driver to maintain steering capability), the oversteering may result in the vehicle missing the upcoming obstacle, going off of the roadway, and being involved in a single-vehicle crash.

Task 5 was divided into multiple subtasks to examine driver crash avoidance behavior with and without ABS. This task sought to assess the prevalence of driver oversteering and examined the effects of ABS instruction and braking practice on successfully avoiding a crash. Task 5.1 used a driving simulator to address this issue. Results of the 1997 simulator study (Task 5.1) [11, 12] also showed that excessive steering can occur during realistic crash avoidance situations. However, this steering was not found to result in a significant number of road departures. Tasks 5.2 and 5.3 [10] were test track studies conducted in 1997-98. Task 5.2 examined driver crash avoidance behavior in a test track environment on a dry, high coefficient of friction road surface. Task 5.3 also studied driver crash avoidance behavior in a test track environment, but on a wet, low coefficient of friction road surface. Results of the 1997-98 test track studies, Tasks 5.2 and 5.3 [10], showed that drivers do tend to brake and steer in realistic crash avoidance situations and that excessive steering can occur. However, a significant number of road departures did not result from this behavior for dry or wet pavement. In addition, presumably due to insufficient brake pedal force application, only 32 percent of subjects experienced ABS activation during the dry pavement scenario, while 97 percent experienced ABS activation on wet pavement where ABS was found to significantly reduce crashes as compared to conventional brakes.

In 2000, Task 6 investigated the effects of ABS during road recovery maneuvers (i.e., when a driver attempts to maneuver an automobile back onto the roadway after a departure). Many road departures occur when the driver drives the vehicle in an essentially straight line that leaves the road. This action may be due to driver inattention, sleepiness, or intoxication. None of these causes are related to the presence or absence of ABS. However, the presence of ABS may or may not influence the ability of the driver to safely maneuver the vehicle back onto the roadway.

Task 7 involved two separate studies that examined the issue of ABS and behavioral adaptation. Several studies have found that people drive faster or more aggressively on test tracks in ABS-equipped vehicles than with conventionally braked vehicles. The goal of this task was to try to determine if these trends occur during typical driving on actual public roads.

Task 7 was divided into multiple subtasks. Task 7.1 [13] involved remote, unobtrusive observation methods to collect data about the behavior (e.g., speed) of drivers. Although a consistent trend was seen in mean speed by brake system for each site with slightly higher speeds being observed for drivers of ABS-equipped vehicles, this trend was not statistically significant. This study showed that type of brake system (ABS or conventional) had no significant effect on

driving speed under the conditions examined. Task 7.2, the subject of this report, sought to assess possible ABS-related behavioral adaptation through the collection of more detailed data about the driving behavior of a small number of subjects using instrumented vehicles in a naturalistic research setting.

Task 8 involved the integration of data from all of the preceding tasks in an attempt to infer why the crash data studies did not find the anticipated increase in safety for ABS-equipped automobiles. To date, the NHTSA studies performed have not found any driver behavior or hardware related issue that appears to clearly contribute to the lack of apparent net crash benefits associated with ABS.

Task 9 involved the dissemination of task results. NHTSA has shared knowledge gained through the program's research efforts with other research organizations, industry, and the public at large through published reports and public presentations.

NHTSA's Light Vehicle ABS Research Program has only been a first step in assessing the anticipated safety benefits from ABS. This program deals solely with trying to learn why the crash data studies did not find the anticipated increase in safety (i.e., reduction in crashes) for ABS-equipped automobiles. The development of countermeasures to resolve any problems discovered is left to future research.

## **2.0 BACKGROUND AND OBJECTIVES**

### **2.1. Behavioral Adaptation and ABS**

One theory that has been developed to explain the lack of apparent ABS crash benefits is that of behavioral adaptation. Behavioral adaptation, in this case, implies that as additional safety features are added to vehicles, drivers may alter their behavior in such a way that results in decreased safety, such as by becoming less cautious or driving more aggressively. This change in behavior may be attributable to drivers' beliefs that the added safety features will prevent them from having a crash or being injured. Along this line, the apparent increase in single-vehicle crashes involving ABS-equipped vehicles may be due to changes in driver behavior (i.e., behavioral adaptation) due to their perceptions of the benefits provided by ABS.

#### **2.1.1. Early Studies**

Studies have been conducted in recent years that show that people may modify their driving behavior in response to the addition of ABS to their vehicle. For example, drivers of ABS-equipped vehicles may operate their vehicles at higher speeds due to the perception that ABS increases the vehicle's handling and braking performance [14]. This increased vehicle speed could result in more single-vehicle, run-off-road crashes, particularly on curved roads.

Smiley and Rochford [15] performed an experiment involving drivers operating test vehicles with and without ABS on a closed course. One set of 20 subjects driving in the ABS active condition received an explanation of the benefits of ABS followed by 30 minutes of practice in an ABS-equipped vehicle performing "emergency" braking maneuvers. The other group of 20 subjects in the ABS condition received the explanation of ABS benefits, but no braking practice. The remaining 40 subjects drove with the vehicle's standard brakes with half of the subjects receiving braking practice and the other half receiving no practice. Results showed that "adaptation was evident on both wet and dry roads" and the adaptation was "in the form of higher speeds for subjects with ABS who had received practice with hard braking." Greater brake pedal forces were also observed for the ABS groups. Behavioral changes were stated to have been associated more with drivers' knowledge that they were using an antilock brake system, rather than as a result of practice with that system.

NHTSA was interested in determining whether ABS-related behavioral adaptation could be observed under real-world conditions. As a result, plans were developed for an observational study of vehicle speed on public roads as a function of brake system (Task 7.1) and an on-the-road naturalistic study of driver behavior with and without ABS (the subject of this report).

#### **2.1.2. National Telephone Survey of Driver Experiences and Expectations Regarding Conventional Brakes versus ABS**

As part of its Light Vehicle ABS Research Program, NHTSA conducted a national telephone survey to assess drivers' knowledge and expectations about ABS and its effect on vehicle performance (Task 2). This information was desired, in part, for use in determining whether the apparent increase in single-vehicle crashes for automobiles was due to drivers' misunderstanding of ABS functionality.

That study found that although most drivers had heard of ABS, many did not know what it did or how it affected vehicle performance, when it functioned, or even if their vehicle was equipped with ABS. Responses indicated that certain types of brake pedal feedback from an activated ABS were often misinterpreted, leading to inappropriate, and in some cases potentially dangerous, driver responses (e.g., possibly taking their foot off the brake pedal). Drivers who owned ABS-equipped vehicles had similar misunderstandings and there was evidence that some of these drivers were overconfident in what ABS could do for them (e.g., ABS allowed them to follow other vehicles more closely). Additionally, a small segment of the respondents expressed a willingness or tendency to change their driving habits if they had ABS. However, this was based on drivers knowing that their vehicle was equipped with ABS.

This survey study can be distinguished from the Smiley and Rochford study in several ways. First it was subjective and not empirical. Second, 65 percent of the drivers of ABS-equipped vehicles did not receive any instruction on the benefits of ABS prior to using the vehicle, whereas all of the ABS drivers had in the earlier study. Lastly, 18 percent of all drivers responding to the survey did not even know if their vehicle was equipped with ABS. Even though the results of the survey did not negate the theory of behavioral adaptation, they raised the question of how could drivers be adapting to something many knew very little about.

#### 2.1.3. Driver Crash Avoidance Behavior with ABS in an Intersection Incursion Scenario

To determine whether some aspect of driver behavior in a crash-imminent situation was counteracting the potential benefits of ABS, NHTSA embarked on a series of human factors studies, which composed Task 5 of the research program. These studies focused on the examination of driver crash avoidance behavior as a function of brake system and various other factors. While these studies were not designed to disprove the theory of behavioral adaptation, a comparison of the results [10] produced evidence that was at odds with an element of the Smiley and Rochford report.

In order to obtain authentic driver behavior in an unsuspected crash-imminent situation, experimenters placed subjects in a test track setting. Two-thirds of the subjects drove an ABS-equipped vehicle while the other one-third drove a vehicle equipped with conventional brakes. The experimenter informed subjects they were being examined to collect data on normal driving behavior and instructed them to maintain the distance separating them from a lead car throughout their drive. After approximately 15 minutes of driving, experimenters suddenly moved a two-dimensional Styrofoam car into their path, eliciting realistic crash-avoidance behavior from the driver. Results of this study showed, in part, that there was no statistical difference in applied brake pedal force between drivers of ABS vehicles and those with conventional brakes under these realistic circumstances. In addition, 69 percent of all subjects participating in the “dry pavement” portion of the test failed to apply sufficient brake pedal force to activate ABS or lock up the vehicle’s wheels.

Comparison of the two studies ([10] and [15]) showed three important similarities. In both experiments, drivers of ABS-equipped vehicles knew the car they were driving had ABS. Moreover, drivers of ABS-equipped vehicles received instruction on how best to operate a vehicle with ABS, while drivers of conventionally braked vehicles did not receive ABS instructions. Lastly, subjects in both studies were given the opportunity to practice braking with the brake system they were to drive with (ABS or conventional brakes) prior to beginning their

test drive. However, no emphasis was made to subjects in the NHTSA study that the focus of the study was how ABS affected the outcome of the crash avoidance situation presented to them.

#### 2.1.4. License Plate Study

To determine whether ABS-related driver behavioral adaptation might have contributed to the perceived lack of benefits of ABS-equipped vehicles in terms of observed crash reductions, NHTSA initiated Task 7 of its Light Vehicle ABS Research Program to observe drivers in their normal driving environment. Task 7.1 [13] involved remote, unobtrusive observation methods to determine whether drivers of vehicles equipped with ABS had a tendency to drive faster than drivers of conventionally braked vehicles. Several locations on public roadways around Ohio were selected as data collection sites. At these sites, the speed and license plate information of passing vehicles were unobtrusively measured and recorded using a laser speed gun, video camera, and laptop computer. Data were collected at each site for specified periods during daylight hours (balanced for morning and afternoon high-traffic periods) in both wet and dry road conditions. Using the license plate number, the VIN number was obtained and then decoded to determine whether each vehicle had ABS. Average speed data for specified conditions and locations were compared for vehicles with ABS versus those without.

The results of this study showed that type of brake system (ABS or conventional) had no significant effect on driving speed under the conditions examined. This finding of no significant speed effects was true for all sites, pavement conditions, and model years of vehicles observed. A consistent, but insignificant, trend was seen in mean speed by brake system for each site where higher speeds were observed for drivers of ABS-equipped vehicles. Significant results that were found included higher speeds for drivers of newer model cars, higher speeds for dry pavement, and that speed varied as a function of location (site). Overall, based on observed vehicle speed results, evidence of passenger car ABS-related driver behavioral adaptation was not observed using the methods employed in this study. Based on these and other related results from NHTSA's Light Vehicle ABS Research Program, behavioral adaptation due to ABS has not been observable during "real world" driving using any methods employed to date. Thus, the results of this study suggest that the apparent increase in single-vehicle crashes involving ABS-equipped vehicles cannot be attributed to behavioral adaptation.

## **2.2. On-Road MicroDAS Study Objectives**

As part of its Light Vehicle ABS Research Program, Task 7.2 further investigated whether the concept of passenger car ABS-related driver behavioral adaptation was an existent and observable phenomenon. Task 7.2 endeavored to collect more detailed data about the driving behavior of subjects using instrumented vehicles in a naturalistic research setting. If differences in speed, acceleration, following distance, and lane change activity could be related to ABS-equipped vehicles, these differences might then be attributable to ABS-related behavioral adaptation.

This report outlines the method and results for Task 7.2 of NHTSA's Light Vehicle ABS Research Program, called the "On-Road MicroDAS Study".



### 3.0 METHOD

An experiment was designed and implemented to determine, in a real-world environment, whether people drive differently in vehicles equipped with antilock brake systems than they do in vehicles equipped with conventional brake systems. A secondary goal of this study was to investigate whether any observable behavioral changes occurred as a function of driver age. This served as a check on the sensitivity of the method used.

#### 3.1. Subjects

Twelve subjects participated in this study. An equal number of subjects were recruited to fill the two desired age groups of 18-25 and 40-60. Subjects were paid \$200 upon completion of their participation.

##### 3.1.1. Subject Selection Criteria

Subjects were selected to meet the following requirements:

- a. Have a valid drivers license without restrictions. If the person's drivers license had a requirement for use of corrective lenses, then the subject was required to wear the lenses at all times while driving the test vehicle.
- b. Hold an automobile insurance policy providing at least the minimum coverage required by state law.
- c. Have a driving record with no DUI convictions and no more than one crash in the last five years; also have no more than three moving violations in the last three years.
- d. Be between the ages of 18 and 25 or between the ages of 40 and 60.
- e. Be healthy and free of any diagnosed ailments, diseases, conditions, or physical handicaps that would adversely affect their driving ability.
- f. Not require any special assistance equipment in order to drive an automobile.
- g. Be willing to sign a waiver to allow video and engineering data taken of the driver while driving to be used without constraint by NHTSA for educational, outreach, and research purposes.
- h. Have a daily (at least 5 days per week) commute of not less than approximately 45 miles one way (for a total round trip mileage of approximately 90 miles) with at least two-thirds of this driving occurring on roadways with a speed limit of 55 miles per hour or greater.

### **3.1.2. Subject Recruitment**

Subjects were recruited by placing advertisements in local newspapers in central Ohio. The ads explained that the purpose of the study was to evaluate sensors and equipment use in the collection of data on naturalistic driving, how the data would be collected, how much they would be compensated for participation, and the time frame in which test participants were needed. Interested persons were instructed to phone NHTSA's Vehicle Research and Test Center (VRTC) to get more information on the study. When prospective test participants called VRTC, the program was described to them as a study of normal driving with the purpose of assessing the performance of data collection equipment; neither antilock brake systems nor behavioral adaptation were mentioned in the description of the study. A list of questions was administered to determine callers' eligibility for participation. Responses to these questions were stored in a spreadsheet database. Based on the noted requirements, persons eligible to participate were identified. Twelve subjects were selected for participation in the study from this list of eligible participants to produce a balance of genders (6 males and 6 females) and to produce the two desired age groups.

## **3.2. Experimental Design**

### **3.2.1. Independent Variables**

The experimental design for this study was a 2×2 mixed within-subjects design [16]. The two independent variables in this study were brake system (within-subjects variable) and subject age (between-subjects variable). Two levels of brake system were used in this study, conventional and ABS. To create the second independent variable, subjects were selected for this study to compose both "younger" (18-25 years) and "older" age groups (40-60 years).

### **3.2.2. Dependent Variables**

Dependent variables of interest included vehicle speed, applied steering wheel angle and rate, applied brake pedal force, lateral acceleration during lane changes, number of lane changes completed, longitudinal acceleration, frequency of ABS activation, and crashes.

## **3.3. Test Vehicles**

Upon signing the informed consent form and the information disclosure statement, each subject was provided with one of seven identical white 1996 Chrysler Concordes. These vehicles were factory equipped with ABS (optional equipment) and cruise control. However, cruise control was disabled on these vehicles for the duration of the study since vehicle speed was one of the dependant variables.

### **3.3.1. ABS Enabling and Disabling**

Subjects drove a test vehicle for one month with the ABS enabled and for one month when the ABS was disabled. The ABS was disabled by removing the ABS fuse from the fuse panel in the vehicle. During the period when ABS was disabled, all logos, dashboard lights, and other indications of ABS presence on the vehicle were also removed or masked.

## **3.4. Instrumentation**

Each test vehicle was equipped with MicroDAS instrumentation. This second-generation, NHTSA-developed data acquisition system, containing sensors and processors, captured travel

speed and lane position, as well as lateral, longitudinal, and yaw rate accelerations. Measurements of driver inputs to direct and control the vehicle were also collected, including steering wheel angle and applied brake pedal force. Measurement of steering wheel position allowed for the calculation of the steering rates. Detection of brake light illumination provided a redundant indicator of when subjects applied the brakes. Time headway was recorded using a Leica headway sensor. A complete list of the recorded data channels is provided in Table 1. Table 2 contains a list of derived parameters. Figure 1 shows the installed MicroDAS processor deck and Figure 2 contains a block diagram of the system.

Table 1. Data Channels Recorded by MicroDAS

	DATA CHANNELS	DEFINITION / MEANING	UNITS / VALUE
1	FTC	Not used	
2	Left turn signal	Left turn signal activated	On / off
3	Right turn signal	Right turn signal activated	On / off
4	Brake light	Brake light indicator	On / off
5	Lateral acceleration	Lateral acceleration	g
6	Longitudinal acceleration	Longitudinal acceleration / deceleration	g
7	Yaw rate	Yaw rate of vehicle	Degrees/sec
8	Left lane tracker	Position of left lane tracker in the lane	Feet
9	Right lane tracker	Position of right lane tracker in the lane	Feet
10	HW	Hand wheel angle	Degrees
11	ABS	On/off measurement of brake system activation detected using Hall effect sensor	On / off
12	Load cell left	Brake pedal force measured by load cell at left 1/3 of brake pedal	Pounds
13	Load cell center	Brake pedal force measured by load cell at center 1/3 of brake pedal	Pounds
14	Load cell right	Brake pedal force measured by load cell at right 1/3 of brake pedal	Pounds
15	Wheel speed FR	Speed of the right front wheel	mph
16	Wheel speed FL	Speed of the left front wheel	mph
17	Wheel speed RR	Speed of the right rear wheel	mph
18	Wheel speed RL	Speed of the left rear wheel	mph
19	Time code ss	Not used	
20	Status 1	Not used	
21	Status 2	Not used	
22	Leica range MSB	Range	Meters
23	Leica range LSB		
24	Range rate MSB	Range rate	Meters/sec
25	Range rate LSB		
26	Curve radius MSB	Radius of curvature	Meters
27	Curve radius LSB		
28	Leica speed MSB	Vehicle speed	Kph
29	Leica speed LSB		
30	Leica acceleration MSB	Not used	
31	Leica acceleration LSB		
32	Leica throttle MSB	Throttle position	Percent Displacement
33	Leica throttle LSB		
34	Vehicle status 1	Not used	
35	Vehicle status 2	Not used	
36	Leica status 1	Not used	
37	UTC time	UTC time of day	HH:MM:SS
38	Lateral degrees	Combine for lateral GPS coordinate	Degrees
39	Lateral minutes		
40	Longitudinal degrees	Combine for longitudinal GPS coordinate	Degrees
41	Longitudinal minutes		
42	GPS speed	Vehicle speed from GPS	mph
43	Ground course	Not used	
44	Video active	Video recording on	1=on, 0=off

Table 2. Parameters Derived from MicroDAS Data

PARAMETERS	DEFINITION / MEANING	UNITS	CALCULATION
Brake pedal force	Total applied brake pedal force.	Pounds	Summation of instantaneous readings of the 3 load cells in the brake pedal.
HW_Angle_Zero	Hand wheel angle zeroed from offset.	Degrees	Handwheel angle is collected with a relative encoder and derived into an absolute position.
HW_Rate	Hand wheel rate.	Degrees per second	Rate of change calculated from the handwheel position data.
Distance	Distance the vehicle traveled.	Feet	Derived from speed data.
Time Headway	Range to forward vehicle.	Seconds	Calculated using data from Leica range sensor
Lane position	Lane position as determined using left and right lane tracker channels.	Feet	Deviation from lane center was calculated and then used to determine mean lane deviation.

Figure 1 is a photograph of the trunk of one of the Concorde test vehicles. It shows the MicroDAS hardware (comprised of two metal cases one on top of the other) installed in the vehicle, with numerous wires connecting the two cases to each other and to the car. The combined unit occupies approximately one sixth of the available trunk space.



Figure 1. Installed MicroDAS Hardware

Figure 2 is a block diagram of the MicroDAS. The system is split into two halves, representing the two metal cases. The first one is the analog and digital event recorder, that interfaces with the vehicle's sensor suite, and the second one is the video event recorder, which contains a quad processor and mpeg encoder. Both halves contain their own power converter, motherboard, and data storage.

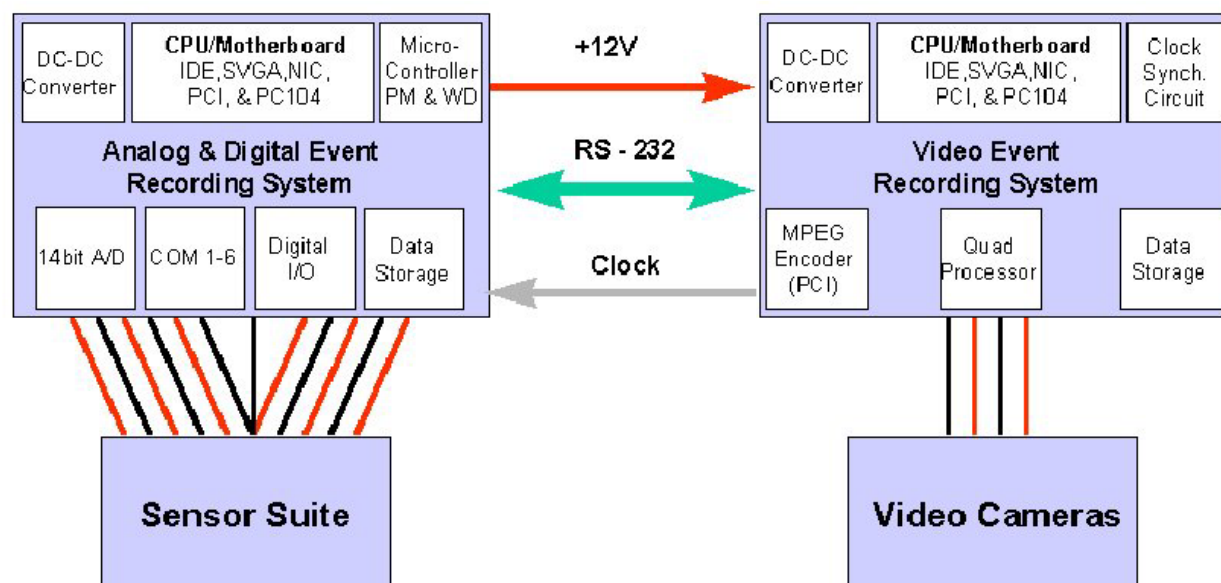


Figure 2. Block Diagram of the MicroDAS

In addition to the sensor data, video images from four camera views were recorded in MPEG format and synchronized to the engineering data. These views included the forward road scene, driver's face, driver's hands, and a view of the right roadside in order to capture any speed limit signs present. This video data was collected for informational purposes but no analysis was planned for driver glance behavior or any other driver behavioral measure that might be extractable. However, when lane changes or other measures such as time headway were not sufficiently addressable using sensor data, video data was used to obtain these measures.

Turn signal activation data and lane tracker position data were collected and post-processed with the intent to find lane line crossings and the number of lane changes performed by subjects. However, due to inconsistencies in turn signal usage, roadways without well-defined lane lines, and other sensor-related problems (such as poor lighting or dirty equipment from bad weather), lane change issues were not sufficiently addressable using sensor data. Therefore video data was used to obtain lane change counts while lane change times were taken from the available sensor data. Also examined using video data was a comparison of how many other vehicles the subjects passed versus how many vehicles passed them during the course of their full trips to work each day. Figure 3 below shows a typical quad-frame video feed from one of the MicroDAS vehicles obtained during the pilot study. The upper left image shows the subject's face, which allows for eye glance analysis when necessary. The upper right image is taken from the interior dome light and shows the driver's hands on the steering wheel and the position of the subject's feet on the pedals. The lower left image is the forward view of the road as seen from the driver's

perspective. The lower right image looks out the passenger side window and shows the subject passing a heavy truck.



Figure 3. MicroDAS Video Image of a Test Subject

ABS activations that occurred while driving were detected through the use of a Hall effect sensor. This device sensed when electrical current traveled from the ABS Electronic Control Unit (ECU) to the ABS pump. All instances of activation were analyzed using both sensor and video data to determine the underlying cause of the activation.

Collection of global positioning system (GPS) data allowed for the determination of where the test vehicle was at any point in time and also assisted with the determination of posted speed limits for roadway segments of interest.

The MicroDAS was programmed to collect data at all times when the vehicle was in operation. All data were captured at a sampling rate of 30 Hz. Further details on MicroDAS are provided in [17].

#### 3.4.1. Data Collection Procedure

Data were offloaded from the MicroDAS at least once a week. Data were typically obtained from the vehicles while the subjects were at work so as to be less obtrusive to the subject's schedule. This helped promote the idea of a naturalistic study by minimizing the number of times the subjects had to meet with the experimenter. Using a second set of car keys to enter the test vehicles, research assistants would remove the data from the vehicle without any assistance from or interaction with the subject. Data was then transported back to the lab for subsequent processing through the exchange of removable hard drives.

### **3.5. Pilot Test Procedure**

A pilot test was conducted to ensure that all sensors were operational and properly calibrated, all data were being successfully captured, subject-handling methods were acceptable, and methods of retrieving data from the test vehicles were also reliable and efficient. Two persons employed



at NHTSA's Vehicle Research and Test Center were recruited to drive instrumented test vehicles to and from work, for a period of two weeks. These pilot subjects were unfamiliar with the purpose of the study. Subjects were told that the purpose of their participation was to assist with MicroDAS development through data collection on normal driving. During the first week the vehicle was configured with ABS disabled. Each day while the subjects were at work, data were downloaded from the test vehicles to ensure that measures of interest were being successfully captured and stored. After one week, the subjects were informed that a checkup of the vehicle identified that some repairs needed to be made to the data acquisition system in the vehicle being driven. The subjects were then each given a different vehicle to drive for the second week. The subjects were informed, without alerting or alluding to the intentions of the study, that this new vehicle was equipped with ABS. At the end of the second week, the test vehicles were returned. All data collected during the pilot test were processed and analyzed to ensure that the effects of interest, if present, could be obtained from the data.

### **3.6. Main Test Procedure**

Subjects were tested in two groups of six. Subjects were provided with MicroDAS-equipped test vehicles to drive on public roadways as part of their normal daily routine for 2 months. Each subject was provided with a list of the vehicle's features (e.g., driver's side air bag, power windows) including the type of brake system that the car was equipped with (i.e., conventional brakes or ABS) (see Appendix A for list). The experimenter, who delivered the vehicle, also presented the list of features verbally in a manner that mimicked a new car salesperson delivering a vehicle to a customer. This ensured that the subjects were fully aware of the vehicle features and their locations. Subjects were also required to read and sign an information disclosure statement and informed consent form (also see Appendix A) that described the program in general terms, the risks, benefits, confidentiality, compensation, and driving requirements.

Half of the subjects drove the vehicle configured with ABS for the first month, while the other half drove the vehicle configured with conventional brakes for the first month. After one month, the brake system was switched for all subjects (i.e., those initially having ABS switched to conventional and those initially with conventional switched to ABS). To permit the switch, subjects were told that a problem was detected with a sensor in the data acquisition system in the vehicle which they were driving and that they would be given a different but similar vehicle to drive for the remaining portion of their participation. Again, a similar list of vehicle features (including safety features) for that vehicle was provided and verbally conveyed to the subject, except with the alternate brake system listed. Subjects were told that ABS was optional on the vehicle and that this vehicle did, or did not, have ABS.

Care was taken to ensure that test participants were not alerted to any special interest in antilock brake systems or behavioral adaptation. The informed consent form, for example, described the study purpose only in general terms, i.e., to gather data on how people normally drive in a variety of driving conditions and evaluate the MicroDAS instrumentation. Also, all driving undertaken by the test participants was fully discretionary and presumably would have taken place regardless of involvement in this study. These factors, together with the absence of an experimenter on the drives, and the unobtrusive nature of MicroDAS, represent a comprehensive effort to gather naturalistic driving data with a minimum of experimental artifacts. The rationale for not drawing extraordinary attention to the brake system was to as closely as possible emulate



the conditions under which a person would purchase a new vehicle in the real world, i.e., they would receive a vehicle owner's manual and perhaps a video cassette tape detailing the features of the vehicle, but would not be forced to view any ABS instructional material or video.

Subjects were instructed that they should not drive the vehicle outside of the state of Ohio. This instruction served to ensure that, in the event of vehicular or instrumentation failures, technicians could be easily dispatched to resolve the problem. This also ensured that the vehicle was likely to be accessible for data retrieval. This restriction was also put in place to prevent subjects from taking road trips they might not otherwise take with their own vehicle and thus logging unnecessarily high mileage on the test vehicles.

### 3.6.1. Post Experiment Questionnaire

When the vehicle was returned at the end of the test, the subjects were paid, informally interviewed, and were asked about any problems or observations about MicroDAS, the test vehicle, or any problems or unusual events that may have occurred during their driving. Each subject filled out a questionnaire during a debriefing session that followed the two-month driving participation. The questionnaire gathered information regarding driver demographics, driving habits, personal vehicle information, past driving experiences, opinions of vehicle design features, and driver perceptions about the performance and handling of the test vehicle. A copy of the actual questionnaire is located in Appendix B.

### 3.7. Data Analysis

Data were parsed into individual route segments to facilitate data analysis. A route segment could be any easily identifiable portion of a subject's outbound or return commuting route that was covered by a single speed limit of either 55 or 65 mph. A **Full Trip** was defined as a subject's entire commute, either from home to work **or** from work to home, but not both. A minimum of 8 full trips (per brake system), which included the segment(s) of interest, was required in order for a route segment to be considered usable. A balanced number of route segments were taken from the outbound and return trip routes.

**Segment 1** was defined for each subject based on route portions consisting of a distance of approximately 4 miles of each subject's route. Segment 1 for each subject remained the same route portion throughout the analysis. Once the first segment was defined for each subject, data analysis was performed on that segment. Upon completion of data analysis for the first segment for all subjects, a second segment for each subject was defined and analyzed. **Segment 2** was 2 miles in length. Some analyses were performed in which Segments 1 and 2 were merged to produce a larger data set called the **Segment Combination**.

Examination of an additional segment that included a stop sign on a 55 mph roadway was planned for each subject. However, no such consistent segment could be found for every subject.

Results for dependent variables for individual segments were averaged for each subject according to brake system. Results were examined by brake system to determine whether differences in their driving behavior were apparent as a function of whether the vehicle was equipped with conventional or antilock brakes. Differences in driving behavior were also assessed as a function of age.

Video data was primarily examined by trip (to or from work). The number of lane changes performed by the subject vehicle, as well as passing statistics, were determined in this manner. Lane change time was an exception, however, as it was examined by route segment in order to minimize data reduction time. Since examination of video data was a lengthier process than that for sensor data, fewer segments were analyzed for this measure than for those measures determined using sensor data. Some measures, such as time headway, used a combination of video and sensor data analysis to obtain results.

Needed data points for individual metrics were obtained or calculated according to the defined segments. The dependent variables and methods for determining their values are summarized in Table 3. Additional details regarding specific analysis procedures for individual metrics are provided in the following subsections.

Table 3. Dependent Variables Used in MicroDAS Study

PARAMETERS	UNITS	PERIOD	DATA SOURCE	CALCULATION
Mean travel speed	mph	trip	sensor	Calculate mean value of travel speed over each trip for time when speed is $\geq 55$ mph
Mean travel speed	mph	segment	sensor	Calculate mean value of travel speed
Maximum travel speed	mph	segment	sensor	Find maximum value of travel speed
Mean percent miles driven $\geq 5$ mph over the speed limit	None	segment	sensor	Create flag channel which equals speed limit + 5mph; Sum distance traveled over all times when travel speed exceeds flag ; Divide above distance value over total length of segment (distance; should be about 2 miles, calculated)
Mean percent miles driven $\geq 10$ mph over the speed limit	None	segment	sensor	Same as above except set flag to speed limit + 10 mph
Maximum lateral acceleration	g	segment	sensor	Find maximum value of lateral acceleration
Maximum longitudinal acceleration	g	segment	sensor	Find maximum value of longitudinal acceleration
Maximum steering rate	degrees per second	segment	sensor	Find maximum value of steering rate
Mean lane deviation	feet	segment	sensor	Calculate mean lane deviation
Number of ABS activations	None	subject	sensor	Find “high/on” points in Hall effect sensor channel, “AND” with brake pedal application; confirm with wheel speeds & video
Time headway	s	segment	sensor & video	Create a channel that divides range by vehicle speed; Clip both metrics to eliminate 0 values; Average all values of this new channel.
Lane change time (all LCs in a segment)	seconds	(Full) trip (outbound only)	sensor & video	(End Time <sub>LC</sub> ) - (Start Time <sub>LC</sub> )
Number of lane changes completed per trip to work (outbound only)	None	(Full) trip (outbound only)	video	Absolute count determined by video
Number of vehicles passed by the subject vehicle (auto / semi)	None	(Full) trip (outbound only)	video	Absolute count determined by video
Number of times the subject vehicle is passed by other vehicles (auto / semi)	None	(Full) trip (outbound only)	video	Absolute count determined by video
Crashes	None	trip	video	Absolute count determined by video

### 3.7.1. Speed Data Analysis

An average of mean travel speed values from each full trip to work or home was calculated for each brake system. Data were only analyzed for times when vehicle travel speed was greater than or equal to 55 mph. A cut off speed of 55 mph was used so that the average of mean travel speed values would not be affected by traffic lights, traffic jams, etc. These averages permitted comparison of mean travel speed by brake system for each subject to assess whether or not individual subjects drove faster with ABS as compared to conventional brakes. Data analyzed for mean travel speed included those obtained in speed limit zones of both 55 and 65 mph.

Mean travel speed values by segment were also calculated. These averages allowed comparison of mean travel speed for a particular speed limit zone by brake system for each subject, to assess whether individual subjects drove faster with ABS as compared to conventional brakes.

Maximum travel speed values were determined for each segment. Average maximum travel speed values were calculated as an average of the maximum values found in each segment of each full commuting trip driven during the given month. Average maximum travel speed values were then compared for all subjects combined as a function of brake system. All dependent variables pertaining to maximum values were averaged in this manner unless otherwise noted.

Mean percent miles driven at a speed greater than or equal to 5 miles per hour over the speed limit were calculated for each subject / segment. Number of miles driven, at a speed greater than or equal to 5 miles per hour over the speed limit, was divided by the total number of miles in a segment to acquire a percentage. This percentage was then used to obtain an average number of miles driven at a speed greater than or equal to 5 miles per hour over the speed limit for each brake system. The same analysis was performed for times when subjects drove at speeds greater than or equal to 10 miles per hour over the speed limit. These same speed criteria used to compare the variables of driver behavior and brake system were also used to compare driver behavior and driver age.

### 3.7.2. Acceleration Data Analysis

Average maximum lateral and longitudinal acceleration values were determined for each subject. This was accomplished by taking the maximum acceleration values for each segment and then averaging them per subject. Average maximum lateral acceleration values were then compared for all subjects combined as a function of brake system to assess whether subjects made more abrupt lane changes in vehicles equipped with ABS versus those without ABS. Maximum lateral acceleration was also compared to driver age. These same analyses were performed for maximum longitudinal acceleration by segment.

### 3.7.3. Lateral Control Data Analysis

Maximum steering rate values, a measure of abrupt lane change behavior, were determined per segment for each subject. Maximum steering rate values were determined for each segment and then averaged per subject. Average maximum steering rate values were then compared for all subjects combined as a function of brake system and driver age.

There was a desire to calculate mean lane deviation measures to compare with brake system and driver age using sensor data for the analysis. However, several issues with the test vehicles and

pertinent instrumentation negatively affected the quality of the lane position data, and thus the lane deviation measure. These issues related to the vehicles' steering system, the roadways, the lane tracking devices, and weather/environmental conditions. The combination effects of these issues made it difficult to obtain consistent or reliable lane position data.

#### 3.7.4. Examination of ABS Activations

ABS activations were identified through examination of Hall effect sensor data. Activations caused by the ABS self-test that occurred each time the vehicle reached a speed of 8 mph after vehicle ignition were not included in the total counts. These self-test activations were identified by observing whether or not the brake light was activated at the time of activation. All remaining valid activations found by this method were examined further by both sensor and video data on a case-by-case basis to determine the circumstances surrounding the event (i.e., hard braking, hitting a bump, low coefficient of friction surface, and so on). Thus, the number of ABS activations per subject was calculated and categorized.

#### 3.7.5. Time Headway Data Analysis

Two time headway metrics, mean time headway and mean minimum time headway, were examined as a function of brake system to assess whether drivers would follow vehicles closer and closer more often if they were driving a vehicle equipped with ABS. These metrics were also examined as a function of driver age.

Time headway was calculated by dividing range (Leica laser range) by vehicle speed for all time frames during a segment when it was known (from video reduction) that a lead vehicle was present, and when range to this forward vehicle was greater than zero. Mean time headway for each subject was calculated by taking a combined average of the mean time headway values from each segment. Mean time headway values were then examined across all subjects according to brake system and age group. A mean minimum time headway metric was similarly examined.

Mean time headway for each subject was calculated by taking an average of the mean time headway values from each segment. Average minimum values for time headway were calculated by taking the mean of each of the individual minimum values per segment of each trip during the two-month period.

#### 3.7.6. Lane Change Data Analysis

Mean lane change time as a function of brake system and age group was examined. All lane change times in a segment were averaged to obtain a mean lane change time per subject. All segment values were averaged for all subjects and compared with brake type and driver age. These averages show the abruptness of lane changes, a measure of driver aggressiveness.

The number of lane changes completed per trip to work (outbound only) was tabulated by video analysis. Averages were taken from the lane change counts for all full trips to work on a subject-by-subject basis and compared by brake system and driver age.

#### 3.7.7. Passing Behavior Data Analysis

Counts were made and averages were taken of the number of vehicles passed by the subject vehicle per trip to work (outbound only). The count values were averaged from all trips for each subject. Counts were also made of the number of times the subject vehicle is passed by other vehicles per trip to work (outbound only). The count values were averaged from all trips for each subject.

#### 3.7.8. Examination of Observed Crashes

Crashes that occurred within the context of the study were identified through self-reporting by subjects and confirmed by examination of video data.

## 4.0 RESULTS

The collected data were analyzed by brake system and subject age. The following sections are grouped according to the eight performance metrics as described in Section 3.7. Within each of these sections the results are examined by brake system and driver age. Unless otherwise noted, each dependent variable utilized the full experimental design in the statistical analysis. Results taken from partial designs are noted with reasoning given as appropriate. Twelve comparable subject datasets were successfully collected during the course of this experiment. Two dependent variables were removed for the reasons described below.

Due to the type of brake pedal force sensors used and the long duration of the data collection effort, dependable brake pedal force data were unfortunately not always available. Over long durations of driving, the load cells were unable to maintain a consistently calibrated zero point, or offset value. The values generated by each of the three load cells during times of no brake applications varied greatly per trip and changed often between brake applications. As a result, the brake pedal sensor data were judged to be unreliable and were not analyzed statistically.

Several issues with the test vehicles affected the quality of the lane deviation measure. These issues include the steering system characteristics, the roadways (e.g., quality of lane markings), the lane tracking devices, and weather/environmental conditions. The combined effects of these issues made it difficult to get consistent, reliable lane position data. As a result, these data were also not analyzed.

Note in the subsequent presentation of findings that results were considered significant if they met the criteria of  $\alpha = 0.05$ .

### 4.1. Speed Results

#### 4.1.1. Speed Results by Brake System

Several vehicle speed metrics were analyzed and compared with the vehicle's brake system and driver's age. These metrics included the mean travel speed, mean maximum travel speed, mean percent miles driven  $\geq 5$  mph over the speed limit, and mean percent miles driven  $\geq 10$  mph over the speed limit. Note that the mean travel speeds are quite high ( $> 65$  mph) because this study only examined data for periods when drivers were traveling 55 mph or faster (as defined in section 3.7). Therefore, the mean travel speeds shown cannot be used to estimate mean travel speed for an entire trip (which would probably involve some low speed driving).

For all of the speed metrics, no significant differences in speed were observed based on the type of brake system used on the vehicle. A summary of the speed results by brake system can be seen in Table 4 below.

Table 4. Speed Results by Brake System

Measured Variable	Segment 1		Segment 2		Combined		Full Trip	
	ABS	Conv.	ABS	Conv.	ABS	Conv.	ABS	Conv.
Mean Travel Speed (mph)	66.74	66.77	65.88	66.31	66.46	66.49	65.12	65.28
Mean Maximum Travel Speed (mph)	71.23	71.44	70.07	70.05	70.83	70.90	73.8	73.7
Mean % of Miles $\geq$ 5 mph Above Speed Limit	39.02	43.26	37.12	40.62	37.31	42.12	–	–
Mean % of Miles $\geq$ 10 mph Above Speed Limit	6.80	7.72	8.02	7.95	7.40	8.04	–	–

#### 4.1.2. Speed Results by Driver Age

When examined by driver age, 9 out of the 14 comparisons of the speed metric by route segment were statistically significant. Two other metrics, from the Segment 2 analyses, showed marginal significance. Table 5 below provides a summary of the speed results by age. The darker shading denotes significant results, while the lighter shading indicates marginal significance ( $0.05 < P \leq 0.08$ ).

Table 5. Speed Results by Driver Age

Measured Variable	Segment 1		Segment 2		Combined		Full Trip	
	Older	Younger	Older	Younger	Older	Younger	Older	Younger
Mean Travel Speed (mph)	65.26	68.25	64.11	67.90	64.66	68.13	63.68	66.72
Mean Maximum Travel Speed (mph)	69.10	73.57	67.75	72.18	68.43	73.09	71.30	76.20
Mean % of Miles $\geq$ 5 mph Above Speed Limit	22.05	60.23	14.61	59.09	15.56	59.85	–	–
Mean % of Miles $\geq$ 10 mph Above Speed Limit	0.76	13.76	0.16	14.50	0.19	14.00	–	–

## 4.2. Acceleration Results

The mean maximum lateral acceleration and mean maximum longitudinal acceleration values were analyzed and compared with the vehicle's brake system and driver's age. These values were obtained by gathering the maximum acceleration values for each segment and then averaging those values per subject according to both main effects.

### 4.2.1. Acceleration Results by Brake System

Analysis of lateral and longitudinal acceleration results by brake system revealed no significant difference in acceleration based on the type of brake system used on the vehicle. A summary of these results is presented in Table 6 below.

Table 6. Acceleration Results by Brake System

Measured Variable	Segment 1		Segment 2		Combined	
	ABS	Conv.	ABS	Conv.	ABS	Conv.
Mean Maximum Lateral Acceleration	0.097 g	0.088 g	0.100 g	0.101 g	0.098 g	0.092 g
Mean Maximum Longitudinal Acceleration	0.080 g	0.075 g	0.068 g	0.081 g	0.076 g	0.077 g



#### 4.2.2. Acceleration Results by Driver Age

When examining results for lateral and longitudinal accelerations by age, only the mean maximum lateral acceleration for Segment 1 was found to be statistically significant. In general, younger drivers exhibited a tendency towards higher lateral accelerations. Table 7 below provides a summary of the acceleration results by age. The darker shading denotes a significant result.

Table 7. Acceleration Results by Driver Age

Measured Variable	Segment 1		Segment 2		Combined	
	Older	Younger	Older	Younger	Older	Younger
Mean Maximum Lateral Acceleration	0.072 g	0.112 g	0.085 g	0.116 g	0.077 g	0.113 g
Mean Maximum Longitudinal Acceleration	0.067 g	0.088 g	0.081 g	0.069 g	0.071 g	0.082 g

#### 4.3. Lateral Control Results

Two lateral control metrics were collected during the study, those being the mean maximum steering rate and the mean lane deviation. The mean maximum steering rate was successfully gathered by segment, averaged per subject, and then compared with the vehicle's brake system and driver's age. As previously discussed, several issues caused lane deviation measures to be removed from consideration.

##### 4.3.1. Lateral Control Results by Brake System

No significant difference in maximum steering rate was observed based on the type of brake system used on the vehicle. This result should not come as a surprise since there were no significant differences observed in the mean maximum lateral acceleration. A summary of the steering rate results by brake system can be seen in Table 8 below.

Table 8. Mean Maximum Steering Rate by Brake System

Measured Variable	Segment 1		Segment 2		Combined	
	ABS	Conv.	ABS	Conv.	ABS	Conv.
Mean Maximum Steering Rate (degrees per sec)	29.1	28.9	49.2	60.1	35.8	39.3

##### 4.3.2. Lateral Control Results by Driver Age

As with the brake system results, driver age did not prove to be a factor in mean maximum steering rate, despite the fact that there was an observed difference in the mean maximum lateral acceleration by driver age. The results are summarized in Table 9 below.

Table 9. Mean Maximum Steering Rate by Driver Age

Measured Variable	Segment 1		Segment 2		Combined	
	Older	Younger	Older	Younger	Older	Younger
Mean Maximum Steering Rate (degrees per sec)	25.8	32.2	60.3	48.9	37.3	37.8

#### **4.4. Examination of ABS Activations**

To assess frequency of ABS activations, ABS activations were determined using sensor data and then further analyzed by both graphical and video means to determine the circumstances surrounding the event. Throughout the entire study, only 17 ABS activation events were recorded. Fifteen of these events had video information that provided sufficient information to support subsequent classification. In two cases, either the video was too dark (due to evening driving) or there was no video at all, so there was no means to determine the cause of the activation event. In 14 out of the 15 cases for which there were video data, analysis revealed that the braking that was associated with the ABS activation was not panic induced (i.e., due to a conflict event). Seven of the 15 cases of ABS activation definitely involved the subject braking while going over a bump or drop off in the road, or other poorly paved transition area (surface irregularities). Another one of the cases included the vehicle ABS startup test. Since the subject happened to be braking at that time, the flag channel did not prevent it from being tabulated as an event. Two more of the 15 cases were created when subjects made aggressive turns while braking over areas with surface irregularities. Two other cases were left undetermined; however, they did not appear to be panic situations. There were also two cases of ABS activation in which the subject was making an aggressive high-speed turn around a sharp curve while braking, and entering the gravel berm area with part of one or two wheels. The last case of ABS activation, which could be construed as a “panic” situation, occurred when a woman from the older age group was accelerating onto the interstate and came too close to a car in front, applied the brakes sharply for just an instant, and then continued accelerating.

No metric comparable to ABS activation was available for conventional brakes, thus the results are limited to those derived as a function of driver age for ABS only. Of the 17 known ABS activations, 10 were by older subjects and 7 by younger subjects. No further detailed analysis was conducted.

#### **4.5. Time Headway Results**

Two time headway metrics were analyzed as a function of brake system and driver age. One was the mean time headway, and the other was the mean minimum time headway. Both metrics were calculated based on information obtained using a headway sensor located on the front of the vehicles. However, due to the failure of the headway sensors to collect sufficient range data in three of the six vehicles used in this study, mean time headway could only be determined for half of the subjects. The missing data were balanced across brake type. These headway sensor failures also reduced the amount of available data for mean minimum time headway calculations. Additionally, there were problems with this data for one of the subjects (this data was eliminated from the calculations). Therefore, inferences made pertaining to the effects of the independent variables on time headway should be viewed with caution.

##### **4.5.1. Time Headway Results by Brake System**

Results for time headway by brake system can be seen in Table 10 below. There were no significant differences between the respective values based on the reduced dataset examined.

Table 10. Time Headway Results by Brake System

Measured Variable	Segment 1		Segment 2		Combined	
	ABS	Conv.	ABS	Conv.	ABS	Conv.
Mean Time Headway (s)	1.58	1.44	1.41	1.28	1.52	1.39
Mean Minimum Time Headway (s)	1.09	0.92	0.96	0.75	1.05	0.86

#### 4.5.2. Time Headway Results by Driver Age

In contrast to the brake system results, significant differences in mean time headway were observed when examined by driver age. Darker shading in the following table denotes these significant results. Again the reader is cautioned that these results are based on a reduced dataset, so inferences should be kept conservative. The results of time headway by driver age can be seen in Table 11 below.

Table 11. Time Headway Results by Driver Age

Measured Variable	Segment 1		Segment 2		Combined	
	Older	Younger	Older	Younger	Older	Younger
Mean Time Headway (s)	1.74	1.27	1.61	1.08	1.70	1.21
Mean Minimum Time Headway (s)	1.19	0.87	1.02	0.74	1.13	0.82

#### 4.6. Lane Change Results

Two lane change metrics were analyzed as a function of brake system and driver age. These metrics were the mean lane change time per trip to work and the number of lane changes completed per trip to work. Mean lane change times were determined by averaging lane change times for each trip to work and individual segments within those trips to obtain the mean lane change times per subject. Number of lane changes completed per trip to work was gathered during the same video reduction phase.

Due to the time-consuming nature of the task of manually counting lane changes using video data, it was necessary to minimize the level of effort involved in the reduction of data without compromising any independent variable treatments. Therefore, only the full trips “to work” (no return trips, i.e., “to home”) were analyzed for these metrics as opposed to other metrics that use data from both the “to home” and “to work” full trips.

##### 4.6.1. Lane Change Results by Brake System

For Segment 1, two subjects in the conventional brake condition were not included in this analysis due to the fact that they made no lane changes during that given month. In both of these cases, the segments were in rural areas on 55 mph state routes where changing lanes was atypical during normal driving.

For Segment 2, three subjects in both conditions were not included in the analysis due to an insufficient amount of data (very few or no lane changes, insufficient number of trips containing lane changes, insufficient sample size) for lane change times during the particular segments of their drives.

The combination of segments data analysis excluded the same three subjects that were excluded for the Segment 2 analysis for the identical reasons. Since these three omitted subjects had some of the longest lane change times (due in part to driving in more rural routes, as well as other reasons), the combination of segments metric had the potential to appear inconsistent with, or lower than, both of the individual segment metrics.

Bearing in mind that subjects were removed from this analysis, no significant differences were found when the three metrics of interest were examined by brake system. A summary of the lane change results by brake system can be seen in Table 12 below.

Table 12. Lane Change Results by Brake System

Measured Variable	Segment 1		Segment 2		Combined		Full Trip	
	ABS	Conv.	ABS	Conv.	ABS	Conv.	ABS	Conv.
Mean Lane Change Time (s)	6.41	5.86	5.28	5.77	5.61	5.63	6.55	6.44
Mean Number of Lane Changes per Trip to Work	—	—	—	—	—	—	17.2	18.3

#### 4.6.2. Lane Change Results by Driver Age

The two subjects who were removed from the Segment 1 analysis due to no lane change activity were balanced across driver age. For Segment 2 and the combined segments analyses, two younger subjects and one older were removed due to insufficient amounts of lane changes made.

Inferences should be made conservatively because the subjects that were removed from this analysis had some of the longest lane change times. As such, significant differences were found when Segment 2 and the combined segments were examined by driver age. A summary of the lane change results by driver age can be seen in Table 13 below, with the significant results shaded.

Table 13. Lane Change Results by Driver Age

Measured Variable	Segment 1		Segment 2		Combined		Full Trip	
	Older	Younger	Older	Younger	Older	Younger	Older	Younger
Mean Lane Change Time (s)	6.65	5.67	6.34	4.51	6.53	4.49	7.05	5.93
Mean Number of Lane Changes per Trip to Work	—	—	—	—	—	—	20.1	15.5

### 4.7. Passing Behavior Results

The two passing-behavior metrics examined were the mean number of vehicles passed by the subject vehicle, and the mean number of times the subject vehicle was passed by other vehicles. All counts generated from this passing behavior activity were collected in conjunction with the lane change counts (video tape data reduction). They were taken for each subject's vehicle per trip to work (outbound only) and averaged for each subject.

#### 4.7.1. Passing Behavior Results by Brake System

As with the previous metrics, there was no significant difference between the observed passing behavior values when examined by brake system, which can be seen in Table 14 below.

Table 14. Passing Behavior Results by Brake System

Measured Variable	Other Vehicles		Semis	
	ABS	Conv.	ABS	Conv.
Mean Number of Vehicles Passed by Subject Going to Work	26.3	31.9	13.2	13.6
Mean Number of Times Subject was Passed by Other Vehicles While Going to Work	13.8	15.3	0.18	0.23

#### 4.7.2. Passing Behavior Results by Driver Age

When examined by driver age, there was one observed difference in the metric mean number of times subject was passed by other vehicles while going to work, denoted by the darker shading in Table 15 below.

Table 15. Passing Behavior Results by Driver Age

Measured Variable	Other Vehicles		Semis	
	Older	Younger	Older	Younger
Mean Number of Vehicles Passed by Subject Going to Work	23.0	35.2	10.7	16.2
Mean Number of Times Subject was Passed by Other Vehicles While Going to Work	22.9	6.2	0.23	0.18

#### 4.8. Examination of Observed Crashes

During the course of this study, two crashes involving the test vehicles were reported by subjects and confirmed by examination of video data. Both subjects were driving a vehicle equipped with conventional brakes, and both subjects were in the younger age group (18-25).

Early in the first month of her two-month participation, one subject struck the rear of a light truck that was in front of her. She was a single, 20 year old female who was driving a test vehicle equipped with conventional brakes. The subject was driving in a small city environment containing traffic lights and moderate traffic on her way home from work. According to the police report, the time was approximately 4:30 p.m. on a sunny Thursday afternoon. Based on video data and subject questioning, it was determined that the subject had come to a complete stop behind the truck in a straight lane at a traffic light. Meanwhile, another vehicle came up from the rear and entered the left turn lane beside her and began talking to her. While the driver in the vehicle beside the subject had her attention, the truck in front of her had moved forward a car length while the traffic signal for that lane still shown red. The left turn light turned green so the car beside the subject started progressing forward while that driver was still talking to the subject. While talking and looking sideways, the subject unknowingly crept forward towards the truck (which had just stopped after moving forward one car length) with the red traffic signal still present. The subject collided with the rear of the stopped truck at an approach speed of less than 5 miles per hour. Damage included a bent bumper on the truck and a bent hood and some broken grill parts on the test vehicle. The incident occurred approximately 50 feet before the intersection. The police report stated there was only moderate damage to both vehicles, both

were fully functional and able to drive away, and the subject was cited as being at fault. Driver inattention and/or distraction appeared to be the primary cause of the crash.

In the middle of his second month of participation, one subject hit a dog while on his way home one evening at around 10:30 p.m. He was a married, 23 year old who was driving a vehicle equipped with conventional brakes. The subject was traveling on a rural road (speed limit 55 mph), it was a very dark night, and his wife was traveling with him. According to the video, the dog sprinted across the road from left to right in front of his vehicle. Although apparently alert, the subject had insufficient time to react to avoid hitting the dog. The right front bumper of the vehicle collided with the side of the dog. The vehicle suffered minor damage including a three-inch crack in the bumper. According to MicroDAS data, the subject was driving approximately 57 miles per hour at the time of the event and exhibited a late braking reaction to the event. He made a hard, quick stab at the brakes one to two seconds after hitting the dog, then letting off the brakes after approximately one second of application. During the jab at the brakes, the subject obtained a maximum brake pedal force of approximately 85 pounds (uncorrected for offset). However, in this scenario the brake system was not a factor in the crash due to delayed application.

#### **4.9. Questionnaire**

A questionnaire was administered at the end of each subjects' participation in this study. The questionnaire used is shown in Appendix B. Selected questionnaire items that were most pertinent to the objectives of this study are described below.

When asked what features their personal vehicle was equipped with, 2/3 of the subjects stated that ABS was a feature on their personal vehicle. Of the subjects who stated their personal vehicles were equipped with ABS, three were in the older age group and five were in the younger age group. An inference may be drawn that these individuals knew some of the potential benefits of ABS.

In addition, regarding the potential for subjects to have knowledge of the potential benefits of ABS, some subjects distinguished between the two brake systems when answering questions about the test vehicle's braking performance. When subjects were asked their opinions of the test vehicles' brakes, two of them made comments addressing the two different brake systems they drove with, and distinguished between them. The first subject stated he was somewhat unsatisfied with the brakes he had during month one (the conventional brakes) and very satisfied with the month two brakes (ABS). This subject commented that the conventional brakes seemed to have a longer stopping distance than the antilock brakes. Another subject, who was very satisfied with the braking performance, commented on liking the standard power brakes but not caring much for the ABS, saying she felt she could not stop "on the dot" with them if she needed to do so. Another subject just specified she was very satisfied with the antilock brakes. Although nothing definitive can be determined from these observations, it is worth noting that some of the participants commented on differences between the two test vehicle brake system conditions.

Examining drivers' willingness to drive faster than the posted speed limit as a function of age group showed differences between the younger and older age groups. For the older driver group, three subjects did not respond to the 35, 45, and 55 mph conditions, but checked that they would

drive 65 mph in a 65 mph speed limit zone. This indicates they may have misunderstood the question. The other three subjects responded exactly the same by consistently stating they would each drive 5 mph over the speed limit for all four of the posted speeds (e.g. drive 40 in a 35 mph zone). The younger subjects' responses varied more than the older subjects, showed a more noticeable tendency to exceed the speed limit, and half of the younger subjects' responses revealed that the degree to which they exceed the speed limit increased as the speed limit increased. For the younger driver group, all six subjects responded to all parts of the question, however, some gave a range of speeds instead of just a single value (e.g., 35-40 in a 35 mph zone). One subject responded that for the 35 and 45 mph speed limits he would drive between 5 mph below and 5 mph above the speed limit, while for higher speed limits the range increased to between 10 mph below and 10 mph above the speed limit. Another younger subject stated driving the speed limit at 35 and 55 mph, but would drive over the posted speeds of 45 and 65 mph by 5 mph. A third younger subject stated the following responses: 35, 50, 62, and 75 mph, respectively, for the 35, 45, 55, and 65 mph posted speed limits. Only one younger subject would drive 5 mph over the speed limit for all four of the posted speeds, with the exception that she would drive a range of 5 to 8 mph over the 65 mph posting. A fifth younger subject stated for each of the four conditions that he would drive up to 5 mph over the speed limit (e.g. 35-40 mph in a 35 mph zone). The remaining younger subject would drive the speed limit posted, except in the 35 mph condition where she would drive 40 mph.

## 5.0 DISCUSSION

### 5.1. Speed

Examination of the speed data by brake system revealed no significant differences in any of the speed metrics collected. Mean travel speed was quite consistent for subjects throughout the two-month period of their participation, as shown in Figure 4. In fact, most individual subject means by brake system did not differ by more than two miles per hour (for either the full trip metric, or the segment metrics). Maximum travel speed and the two mean percent miles driven over (5 and 10 mph) the speed limit were all approximately the same when analyzed according to the type of brake system available on the vehicle, as shown in Figures 5-7.

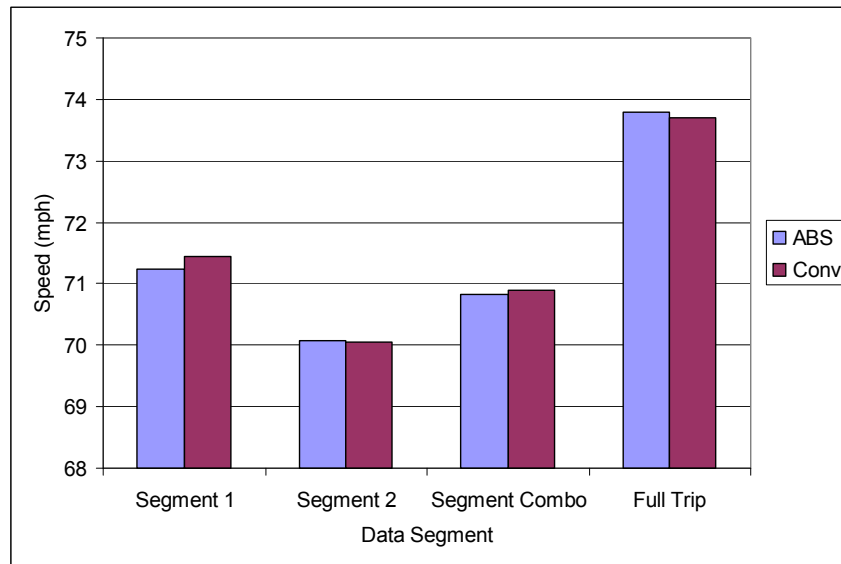


Figure 4. Mean Travel Speed as a Function of Brake System

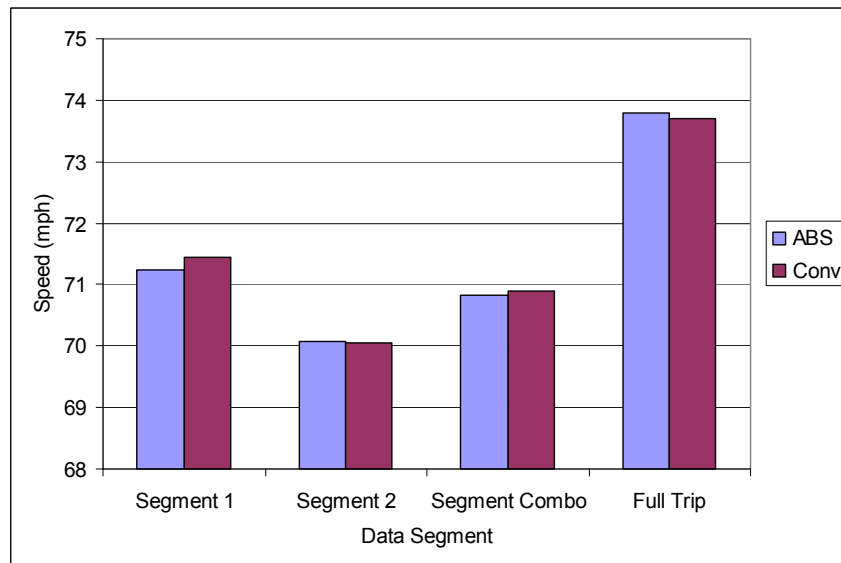


Figure 5. Maximum Travel Speed as a Function of Brake System



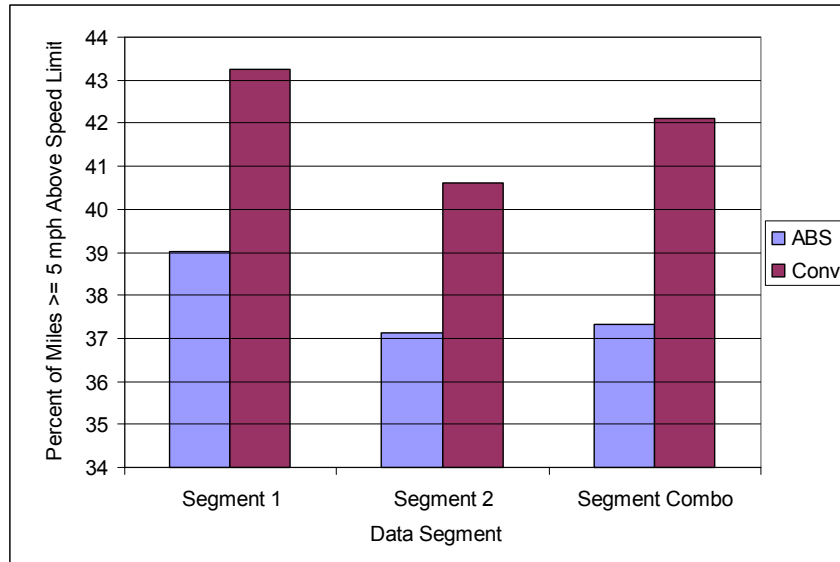


Figure 6. Mean Percent of Miles  $\geq$  5 mph Above Speed Limit as a Function of Brake System

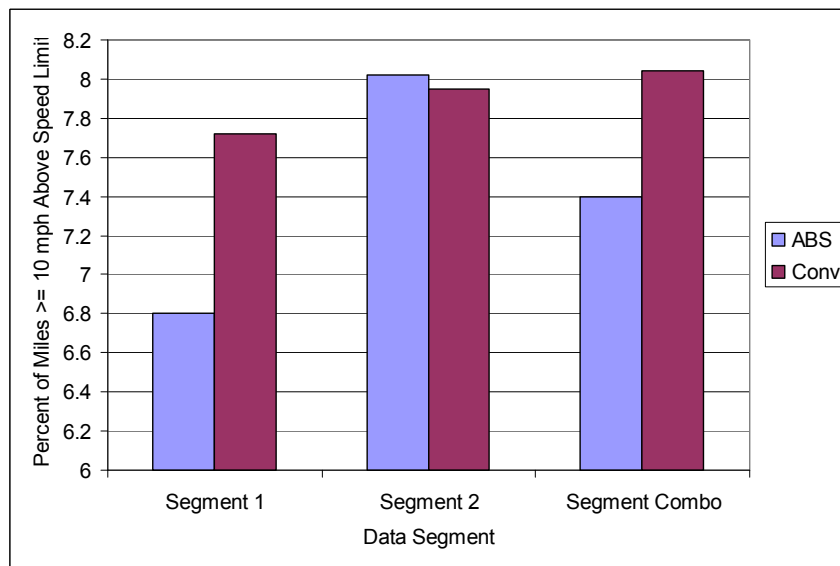


Figure 7. Mean Percent of Miles  $\geq$  10 mph Above Speed Limit as a Function of Brake System

On the other hand, numerous differences were evident in the analyses of speed by driver age. No matter which portion of the driving data was examined (each segment, combined, or full trip), younger drivers consistently drove faster (3-5 mph), and drove faster than the speed limit more often (13-44 percent of the time), than older drivers. This pattern was true for the mean travel speed by segment(s) and combination, despite the fact these were not significantly different.

Figure 8 shows that travel speeds across the data portions (Segments 1 and 2, segment combo, and full trip) examined ranged from approximately 66 mph to 68 mph for younger drivers and from approximately 63 mph to 65 mph for older drivers. Maximum travel speeds for these data portions ranged from 72 mph to 76 mph for younger drivers and from 67 mph to 71 mph for

older drivers, as shown in Figure 9. Figure 10 shows that 60 percent of younger drivers drove 5 mph faster or more than the speed limit (for Segments 1, 2, and the segment combo), while only 14 – 22 percent of older drivers did. Figure 11 shows that 14 percent of younger drivers drove 10 mph faster or more than the speed limit (for Segments 1, 2, and the segment combo), while less than 1 percent of older drivers did.

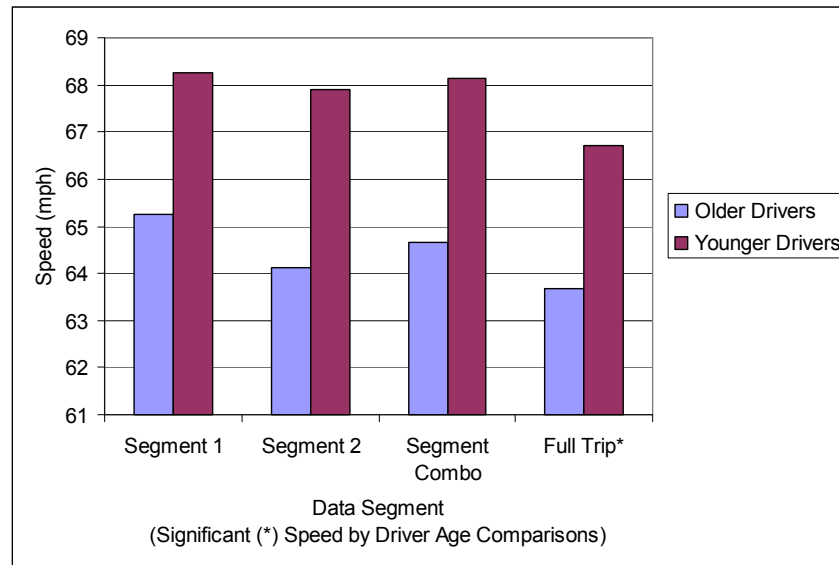


Figure 8. Mean Travel Speed as a Function of Driver Age

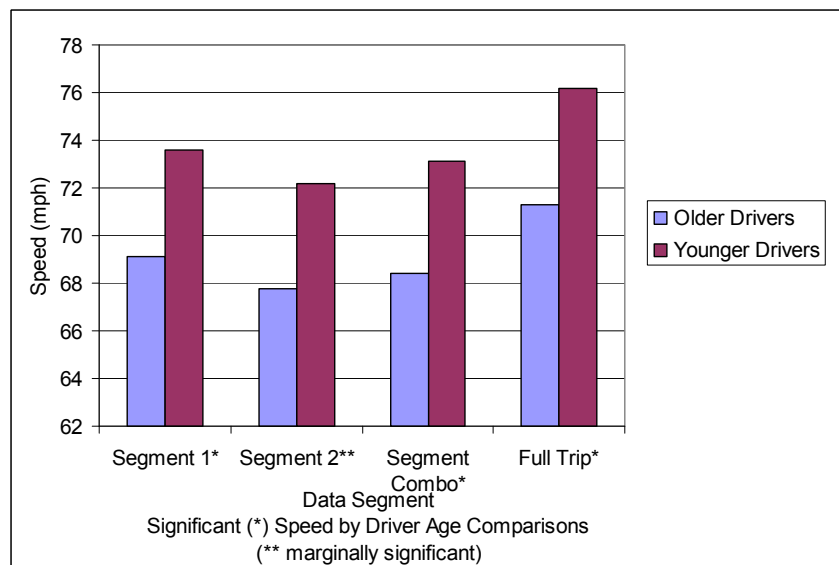


Figure 9. Maximum Travel Speed as a Function of Driver Age

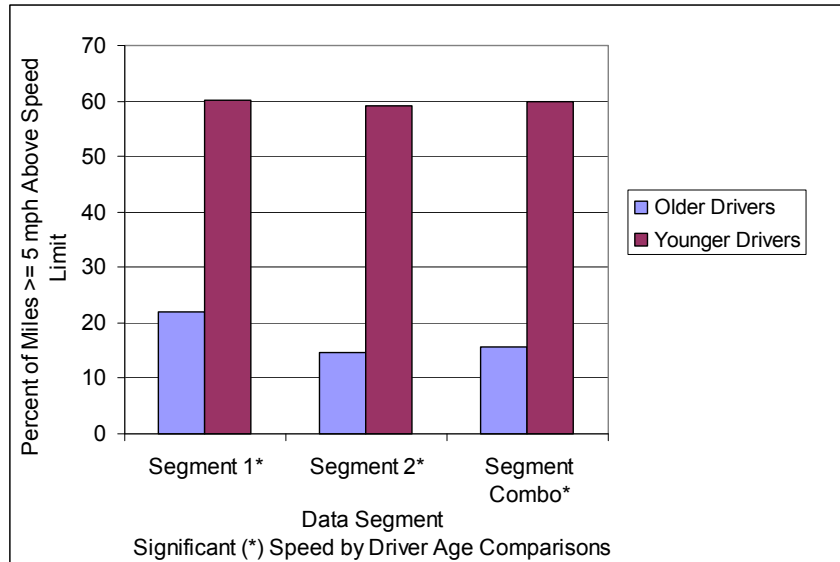


Figure 10. Percent of Miles  $\geq$  5 mph Above Speed Limit as a Function of Driver Age

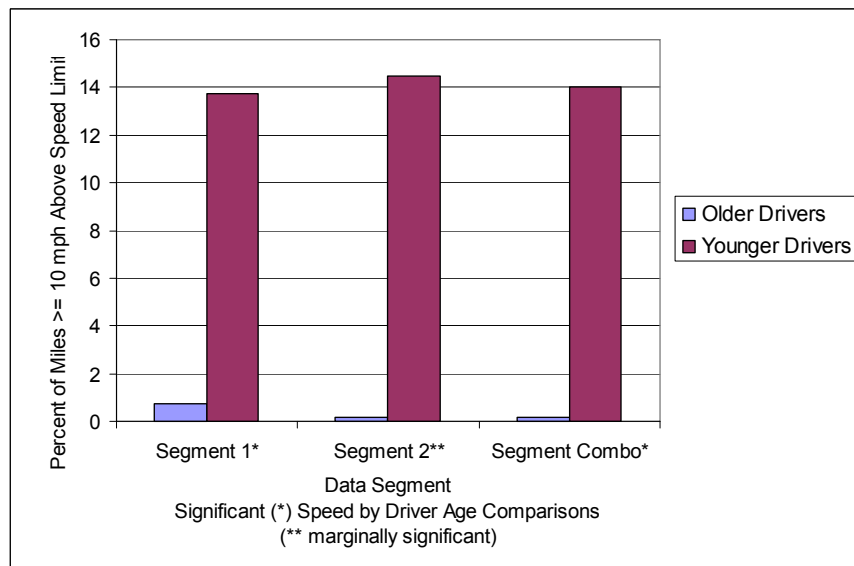


Figure 11. Percent of Miles  $\geq$  10 mph Above Speed Limit as a Function of Driver Age

Seasoned drivers who log numerous miles each year are more likely to be familiar with the safety concerns, legal aspects, and subsequent financial consequences associated with risky driving (i.e., exceeding speed limits, aggressive acceleration and braking, fast lane changes, following too closely, etc.). This was reflected in older subjects' more conservative driving behavior observed in this study.

These findings suggest, as did a previous NHTSA study [13], that behavioral adaptation to ABS, though theoretically possible, is not an observable phenomenon in the real world. The Smiley and Rochford test track study on behavioral adaptation [15] found that vehicles equipped with ABS were driven faster than conventionally braked vehicles. However, the vehicle speeds

collected during this study did not show a significant difference in speed as a function of brake system.

The authors believe that the current study has enough sensitivity so that, if there were speed differences due to driver behavioral adaptation to ABS, such differences would have been detected. The procedure used had no difficulty in detecting the (anticipated) effects of driver age on driving speed.

Changing the  $\alpha$  level used for statistical significance would not change the above conclusion. The observed speed differences due to type of brake system were miniscule. In general, slightly higher speeds were observed when subjects were driving the conventionally braked vehicles.

## 5.2. Accelerations

Maximum lateral and longitudinal accelerations were examined. The analyses of mean maximum longitudinal acceleration examined by both brake system and driver age revealed no significant differences between ABS and conventional brake systems. No significant differences in maximum lateral acceleration were found as a function of brake system, as illustrated in Figure 12. However, mean maximum lateral acceleration was found to be statistically significant as a function of driver age for Segment 1, as illustrated in Figure 13, but not for Segment 2 or the segment combination. For both segments and the segment combination however, the trend was that older subjects had lower maximum lateral accelerations than younger subjects did, as seen in Figure 13 below. This figure shows that mean maximum lateral acceleration across Segment 1 was approximately 0.11 g for younger drivers, while older drivers were in the 0.07 g range. In summary, younger drivers appear to have made more aggressive lane changes, but brake system had no effect on the manner in which drivers made turns, maneuvered around curves, or changed lanes.

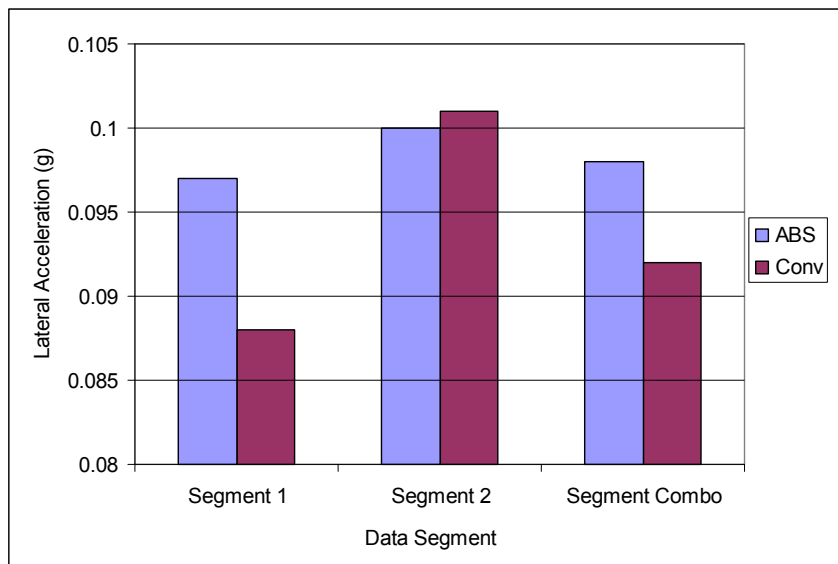


Figure 12. Maximum Lateral Acceleration as a Function of Brake System

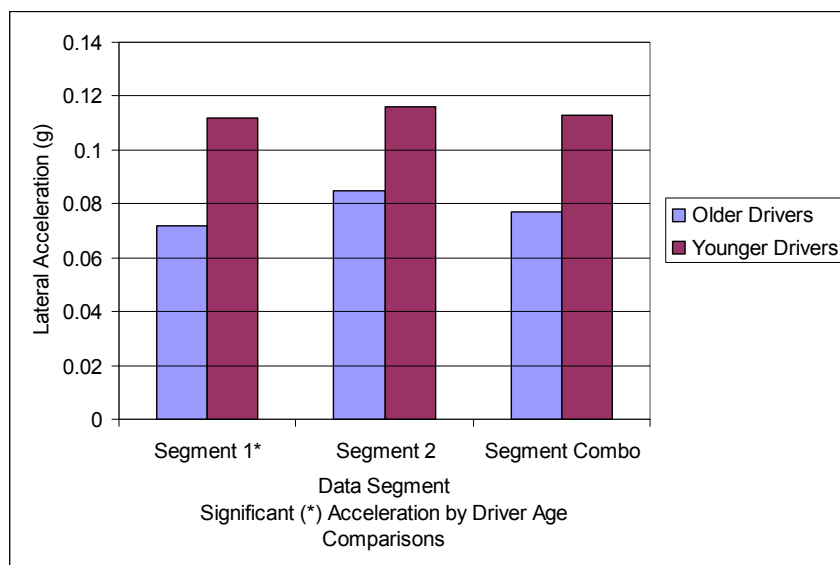


Figure 13. Maximum Lateral Acceleration as a Function of Driver Age

Longitudinal acceleration includes not just how quickly a car accelerated, but also how quickly it decelerated. In Smiley and Rochford [15], greater brake pedal forces were observed for the ABS groups. Brake pedal force and longitudinal deceleration are directly proportional as long as the vehicle is operating in the linear range (not locked up or ABS activated). So despite the fact that brake pedal sensor data were not directly analyzable, it is fair to say that because there were no differences in longitudinal deceleration, there could not have been any differences in brake pedal force either.

The results also contradict a finding of an earlier test track study, described in Smiley and Grant [18]. This study was a reevaluation of the data from the previous Smiley and Rochford study. It found that subjects driving ABS-equipped vehicles had statistically higher maximum and mean accelerations (i.e., higher decelerations). However, the current experiment found that the type of brake system used had no observable effect on that type of acceleration. Therefore drivers in the real world, driving vehicles equipped with ABS, do not appear to accelerate or decelerate faster or apply higher brake pedal forces than drivers in conventionally braked vehicles.

### 5.3. Steering

The analysis of steering inputs revealed nothing in the way of significant differences between brake types or driver age groups. There were no observable trends either. For example, Table 9 showed that mean maximum steering rate was inconsistent between segments (i.e., older subjects had higher rates than younger subjects on one segment, but lower rates on the other), but when segments were combined the mean rate was basically the same for both age groups. High angular inputs produce turns with rapidly decreasing radii, and decreasing the radius of a turn while maintaining the same (or similar) velocity would result in higher lateral acceleration. Therefore, no significant difference in the mean maximum steering rate substantiates the general lack of differences in mean maximum lateral acceleration.

#### 5.4. ABS Activations

As previously mentioned, only 17 ABS activation events were recorded throughout the duration of the study. Of the 17 activations, only one was found to be associated with a crash avoidance maneuver. Based on the results of the ABS activation analysis for this study, it appears people did not use their brakes to the extent required to activate ABS under normal driving circumstances. Braking over surface irregularities was the leading cause of ABS activation.

#### 5.5. Headway

Analyses of mean time headway and minimum time headway were performed as a function of both brake system and driver age. Note that these findings are based on a reduced dataset due to instrumentation difficulties, and therefore interpretations should be used with caution. Results by type of brake system revealed nothing of statistical significance for both performance metrics. Drivers of vehicles equipped with ABS did not follow the car in front of them any closer than those drivers in conventionally braked vehicles, as shown in Figure 14. However, the same cannot be said about driver age, where the results revealed that older drivers maintained longer following distances than younger drivers.

Figure 15 shows that in both segments and the segment combination, older subjects exhibited significantly longer mean time headway than younger subjects. Time headway results by age across the data portions examined (Segments 1, 2, and the segment combo), ranged from approximately 1.1 to 1.3 seconds for younger drivers and from approximately 1.6 to 1.75 seconds for older drivers. This difference was approximately half of a second. The tendency for older drivers to maintain a longer following distance in each segment extended to the minimum time headway values, where differences of approximately 0.3 seconds were observed, though they failed to reach the level of statistical significance.

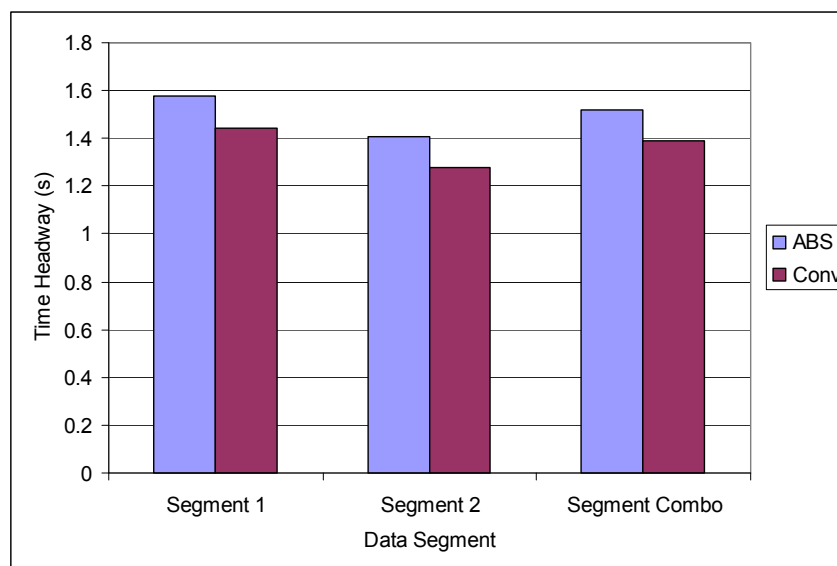


Figure 14. Mean Time Headway as a Function of Brake System

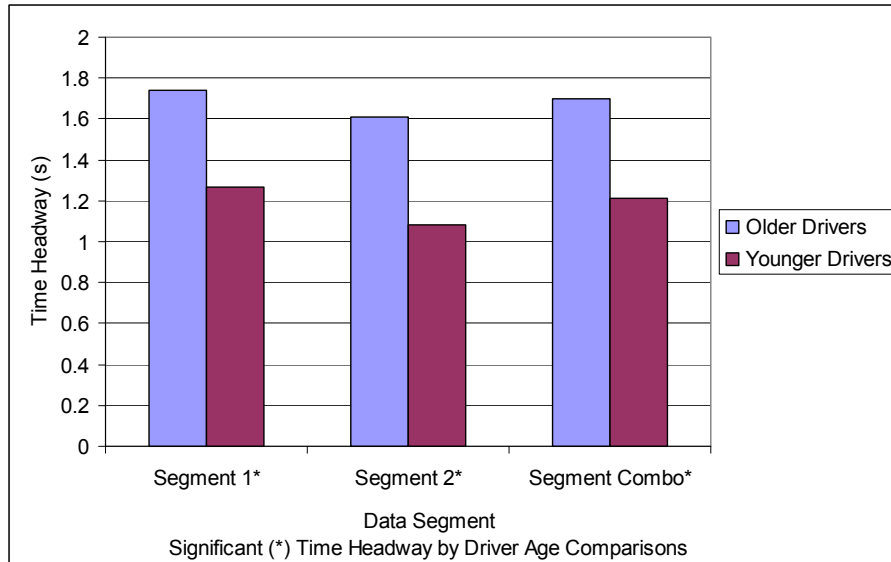


Figure 15. Mean Time Headway as a Function of Driver Age

## 5.6. Lane Changes

The lane change analyses revealed nothing in the way of significant differences between brake types, suggesting once again that drivers do not change their driving habits based on the type of brake system provided on a vehicle. A graph of lane change completion time as a function of brake system is shown in Figure 16. There was one observable difference in lane change activity based on age. Examination of mean lane change completion time revealed that older drivers took 1.8 – 2 seconds longer to change lanes than younger drivers did in Segment 2 and the segment combination. Older drivers consistently changed lanes slower than younger ones did and were more consistent also, with values between 6 and 7 seconds per lane change. These differences in lane change times, supportive of the lower lateral accelerations previously mentioned, can be seen in Figure 17. This figure shows the differences between lane change times for younger and older drivers. Significant differences can be seen in Segment 2 and the segment combination, where older drivers took more than 6 seconds to change lanes but younger drivers' times were approximately 4.5 seconds per lane change.

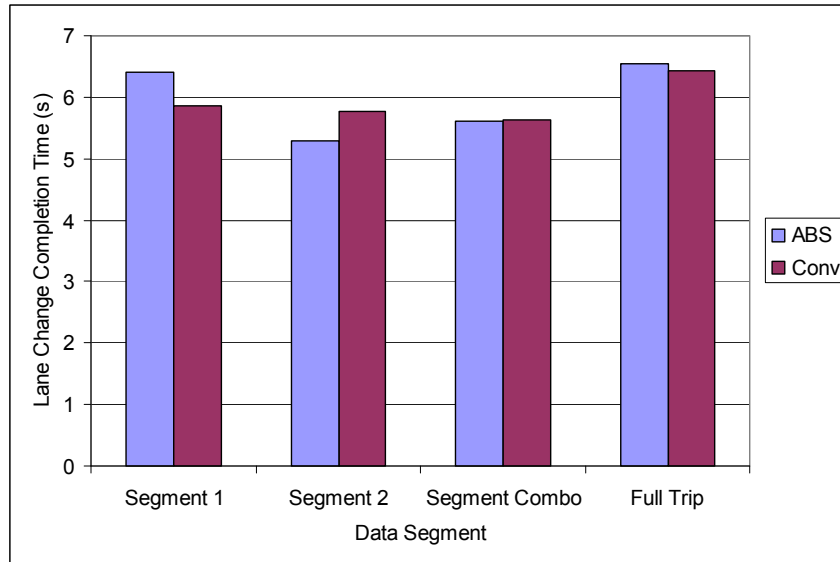


Figure 16. Lane Change Completion Time as a Function of Brake System

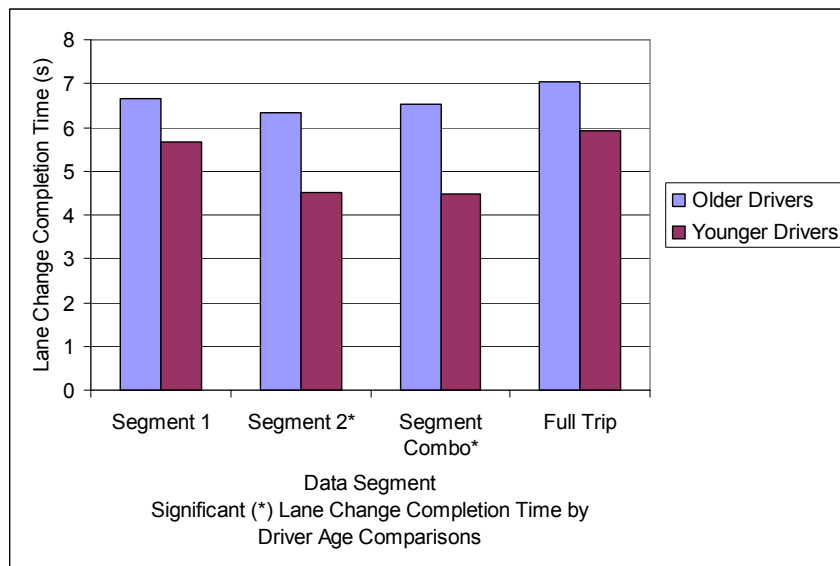


Figure 17. Lane Change Completion Time as a Function of Driver Age

### 5.7. Passing Behavior

Results for the analysis of passing behavior suggest again that drivers do not exhibit differences in their behavior based on the type of brake system provided on a vehicle, as illustrated in Figure 18. The analyses of passing behavior found that older drivers were more likely to be passed by other vehicles, shown in Figure 19 below. The figure shows that the mean number of times older drivers were passed by other vehicles was approximately 23 times per trip to work, while younger drivers were only passed approximately 6 times. This is consistent with the speed analysis data, where it was shown that older drivers drove slower and were less likely to travel for extended periods over the posted speed limit.



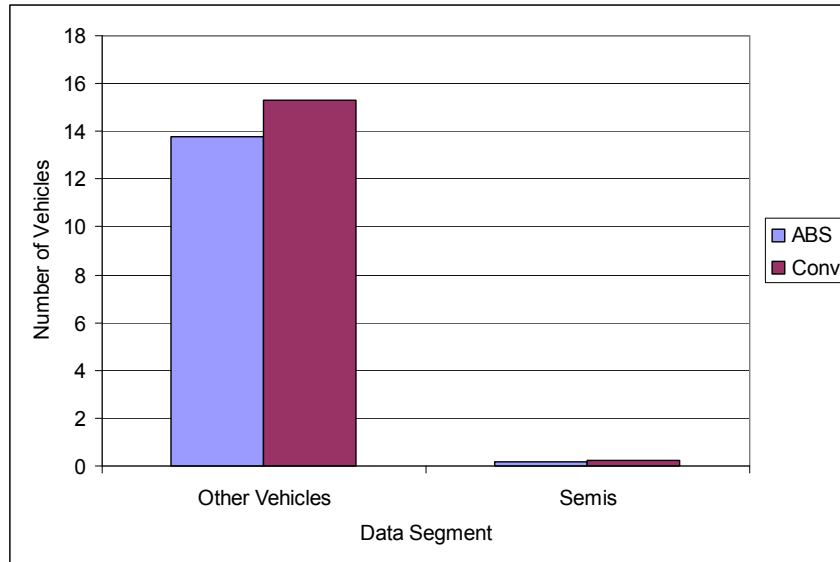


Figure 18. Number of Times Subject was Passed by Other Vehicles as a Function of Brake System

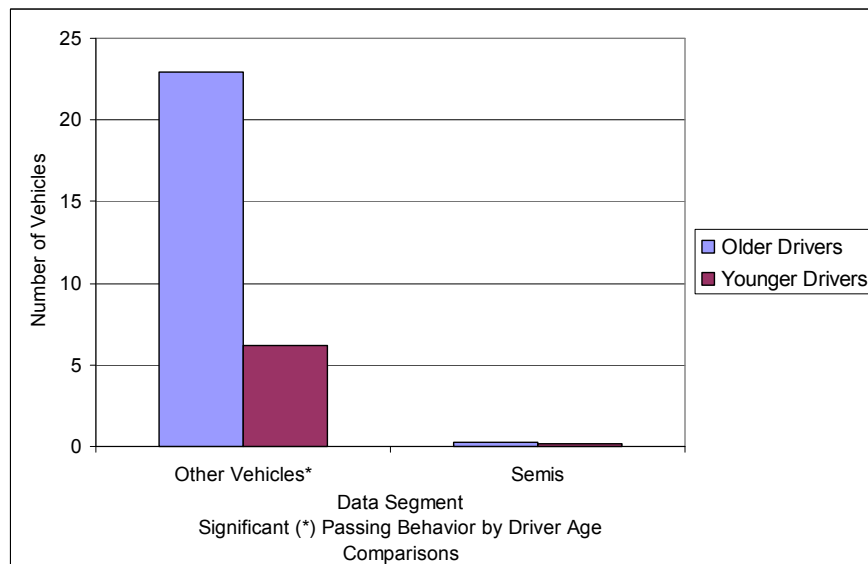


Figure 19. Number of Times Subject was Passed by Other Vehicles as a Function of Driver Age

## 5.8. Crashes

Two crashes occurred during the course of this study. One involved a subject colliding into the rear of another vehicle near an intersection while distracted by a person in an adjacent vehicle. The other crash involved a subject hitting a dog as it crossed the road in front of the test vehicle. Both subjects were driving a vehicle equipped with conventional brakes, and both subjects were in the younger age group (18-25). In both cases, the type of brake system was not a factor.

## **5.9. Questionnaire**

Questionnaire results were used to assess subjects' experience in the study, their knowledge of ABS, and whether they had any tendency to exhibit risky driving behavior. Results showed that 2/3 of the subjects knew that their personal vehicles were equipped with ABS. While this result was higher than that found in a recent NHTSA survey (41.7 percent)[9], an inference may be drawn that these individuals knew some of the potential benefits of ABS. Secondly, the responses assessing a driver's willingness to drive faster than the posted speed limit (at 35, 45, 55, and 65 mph) showed that a majority of the subjects indicated they would in fact drive faster. However, these opinions were elicited without reference to brake type and were also not substantiated by the recorded data. Examining drivers' willingness to drive faster than the posted speed limit as a function of age group showed that the younger subjects' responses varied more than the older subjects, showed a more noticeable tendency to exceed the speed limit, and half of the young subjects' responses revealed that the degree to which they exceed the speed limit increased as the speed limit increased.

When subjects were asked their opinions of the test vehicles' brakes, only two of them distinguished between the two months when they had different brake systems. Two subjects stated specifically that they were satisfied with the ABS, but were less satisfied with the conventional brakes, while another subject stated that the ABS would not allow her to stop "on the dot" like the standard brakes would. Another subject just specified she was very satisfied with the antilock brakes. Although nothing definitive can be determined from these observations, it is worth noting that at least some of the participants were aware that their vehicle's brake system did change and that they paid attention to the performance of the brake system.

## 6.0 CONCLUSIONS

This study examined the effects of brake system and driver age on the driving behavior and performance of subjects driving instrumented vehicles on public roads. The purpose of the study was to assess whether people might drive differently with ABS than they would with conventional brakes. Driving performance metrics included four speed evaluations, lateral and longitudinal accelerations, steering rate, mean and mean minimum time headway, lane change activity, and passing activity.

The results of this study showed that the type of brake system (ABS or conventional) had no significant effect on any of the driving performance metrics examined. In addition, no significant interaction effects were found when examining these metrics. However, some significant effects of driver age were found on metrics including speed, lane change completion time, and numbers of vehicles that passed the subject vehicle. These age effects demonstrate the tendency of older drivers to drive more conservatively. The fact that significant differences were found when the data were examined as a function of driver age shows that the lack of significant results for brake system is probably not due to a lack of sensitivity in the test method.

Only 17 ABS activation events were recorded throughout the duration of the study in which 12 subjects each drove for 1 month with ABS and 1 month with conventional brakes. Of the 17 activations, only one was found to be associated with a crash avoidance maneuver while the rest are believed to be due to braking over surface irregularities. The fact that ABS rarely was engaged suggests that people either did not tend to get into panic braking situations or they did not tend to exert enough force on the brake pedal to cause the ABS to activate. The low incidence of ABS activations has been observed in other NHTSA study in which subjects were placed in a crash-imminent situation [10]. This repeated finding suggests that low ABS activation rates are prevalent in the real world. If the average driver is unlikely to activate ABS in real world driving, then the likelihood that ABS could help them prevent a crash is equally unlikely.

This NHTSA effort to assess ABS-related behavioral adaptation under real-world conditions has produced data contrary to earlier test track studies. When using ABS, drivers were not found to drive faster or accelerate faster than they did with conventional brakes. With ABS, they also were not found to change lanes more often or exhibit maneuvers resulting in higher lateral or longitudinal accelerations than with conventional brakes. Moreover, this study validates other recent NHTSA studies that found lack of observable differences in speed and brake pedal force exhibited by drivers as a function of brake system. These results continue to suggest that the inclusion of ABS has no apparent impact on the manner in which a vehicle is driven, especially under normal operating conditions. In summary, based on the research performed by NHTSA to date, it does not appear that previous increases in run-off-the-road single-vehicle crashes can be attributed to ABS-related behavioral adaptation.

## 7.0 REFERENCES

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**TEST PARTICIPANT INFORMATION SUMMARY**

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**Project Title:**        **New Vehicle Instrumentation Validation Study and Data Collection**

**Principal Investigator:** If you have questions at any time regarding this study please contact Liz Mazzae of the National Highway Traffic Safety Administration (NHTSA) at the address and/or telephone number given below:

Liz Mazzae  
NHTSA Vehicle Research and Test Center (VRTC)  
10820 SR 347  
East Liberty, OH 43319  
Phone:(800) 262-8309 or (937) 666-4511

We do not anticipate that any changes to procedures will take place during this study, however, any new information developed during the course of the research that may affect a subject's willingness to participate will be provided to you.

**Study Description:** You have been invited to participate in an effort to assess the performance of a state-of-the-art automotive data acquisition system called the Micro Data Acquisition System, or "Micro DAS". The United States Government's National Highway Traffic Safety Administration (NHTSA) is developing this instrumentation for collecting information to describe how average people drive. In order to ensure that the data acquisition equipment functions as intended, it must first be tested to ensure that all sensors and computing equipment are performing adequately and without failure. This testing will provide the needed data for this data acquisition system performance verification. This information is important for the design of safer automobiles and automotive safety systems.

The vehicle which we will provide you with will be instrumented with a Micro DAS. The Micro DAS contains sensors which measure certain aspects of vehicle operation, vehicle motion, and driver actions. The system also contains video cameras which capture images of driver actions and the environment in which the vehicle is being driven (e.g., driver's hand position on the steering wheel, forward road scene). These sensors and video cameras are located in such a manner that they will not affect your driving, the vehicle's performance, or obstruct your view while driving. The information collected using these sensors and video cameras is recorded onto data storage media for subsequent analysis by research staff.

As a side effort, we are interested in acquiring your opinions regarding the design of new vehicles. Your opinions regarding the features and functions of new vehicle systems and design features may help automobile manufacturers to design better and safer cars. At the end of your participation, you will be asked to complete a brief questionnaire regarding this topic.

**Driving Requirements:** Participation in this study will involve driving an instrumented research vehicle during your normal daily activities for a period of approximately two months. This vehicle will be provided to you by NHTSA for use over the two-month period upon signing of the informed consent and information disclosure statements contained in this form. You have informed NHTSA that your normal daily, weekday routine includes driving an automobile to commute to work and that the distance of the commute is approximately 45 miles in each

direction for a total of approximately 90 miles traveled round trip each work day. You have submitted to NHTSA the details of the route you typically take to travel to work and reported that a minimum of two-thirds of this weekday driving is conducted on public highways having a speed limit of 55 miles per hour or greater. By agreeing to participate in this study, you agree to drive the research vehicle to and from work every work day for a period of approximately two months. You are permitted to use this vehicle as you would your own vehicle to run errands, etc, as well as to drive on weekends. However, by signing the informed consent statement below, you agree that you will not drive the research vehicle outside the geographical boundaries of the State of Ohio. You are not permitted to allow any other person to operate the vehicle during the time it is in your possession. You will be responsible for purchasing the fuel required to operate the vehicle as you would your own vehicle.

**Use of the Research Vehicle:** Please drive as you normally would while participating in this study. Do not stray from the specified route which you normally take to work. In the event that you unintentionally leave the specified route, please return to the specified route as soon as it is safe to do so.

You remain responsible for your driving during this testing. When on public roads, you are not exempt from any laws. Be aware that crashes can happen at any time when driving. Crashes that occur on public roads must be reported to law enforcement officials. You must notify the principal investigator in the event of a crash. We will contact law enforcement officials if you have been unable to do so. **It is very important to always remember that you, as the driver, are in control of the vehicle and are fully responsible for driving safely at all times.**

The contractor responsible for conducting this testing, the Transportation Research Center Inc. (TRC), will maintain insurance that will cover you in the event of a crash. This insurance will provide coverage for injuries to yourself up to a limit of \$10,000.00. Coverage will also be provided for injuries to others, including passengers in the research vehicle and the driver and any passengers of other vehicles involved in the crash, as well as damages resulting from any crashes occurring during your participation in this study, up to a \$1,000,000 limit. Except to the extent covered by such insurance policy, neither the TRC nor NHTSA will be responsible for your actions during this study nor will they indemnify you or otherwise compensate you for any problems arising out of your actions or the normal risks associated with driving. However, you will not be liable for loss or damage to the MicroDAS equipment, the research vehicle, or other test equipment during the test unless there is gross negligence on your part.

**Risks:** During your participation in this study, you will be subject to all risks normally associated with driving on public roadways. There will be no risks involved in this testing beyond those which are normally associated with driving on public roadways. All driving which you will do in this study will be of your own volition. You will not be instructed to drive any particular route at any particular time, other than to drive to and from work as you normally would. You will not be asked to perform any specific tasks while driving for this study. While driving for this study you will not be asked to perform any unsafe driving acts. In the event of an unforeseen incident, you should contact the authorities immediately and then contact the Principal Investigator at your earliest convenience. There are no known physical or psychological risks associated with participation in this study beyond those normally found in driving.

**Vehicle Checkups and Data Retrieval:** At regular intervals, possibly as frequently as once per week, the vehicle must be made available to NHTSA in order to allow data to be downloaded from the onboard data acquisition system. These data retrieval activities are expected to be brief in duration. In addition, after approximately one month from the time you initially receive the vehicle, you will be required to bring the vehicle to a location specified by the Principal Investigator in order to allow the vehicle to undergo a brief checkup to ensure it is running properly and all instrumentation is functioning as expected. These meetings will be arranged to take place at a time and place which is convenient both for you and for NHTSA. If possible, for your convenience NHTSA will dispatch a technician to your home or workplace to perform these tasks. Depending on the condition of the vehicle and/or the nature of the tasks which need to be performed, it may be necessary for you to bring the vehicle to NHTSA at 10820 SR 347 in East Liberty, OH.

**Vehicle Maintenance and/or Service:** The vehicle will be provided to you in good condition. All routine maintenance will be completed before you receive the vehicle such that none will be necessary during the time that the vehicle is in your possession. In addition, Roadside Assistance coverage has been acquired for you for the duration of your participation in this study through the American Automobile Association. When necessary, you may contact AAA by phone at the following number:

AAA 24-Hour Roadside Assistance: (614) 431-3388

In the event of an unexpected vehicular failure, you should react to remedy the failure in the following manner according to the nature of the problem:

**Minor failure:** If at any time the vehicle experiences a minor failure (e.g., flat tire, battery problems, locked key in the car), you should use the mobile phone located in the vehicle's trunk, or a public phone, to contact AAA at (614) 431-3388 for roadside assistance in resolving the problem.

**Moderate or serious failure:** During business hours (nominally 7:30 am to 5 pm, if you detect any sign of vehicular malfunction other than a minor failure, you must contact the Principal Investigator at (800) 262-8309 ***immediately*** to report the trouble. When calling, you should ask for the Principal Investigator by name, Liz Mazzae, and identify yourself as a ***participant in the "New Vehicle Instrumentation" study***. Upon contacting the Principal Investigator, you may be instructed to contact AAA at (614) 431-3388 for service or arrangements may be made by the Principal Investigator to retrieve the vehicle from you for a brief period of time for servicing by NHTSA.

**Note:** At any time when contacting the Principal Investigator by phone, in the event that Ms. Mazzae is unavailable, please ask to speak to Frank Barickman or Jan Cooper for assistance.

**Severe failure:** If the vehicle becomes ***undrivable*** for any reason *during normal business hours*, you must use the mobile phone located in the vehicle's trunk to notify the Principal Investigator of this condition and then contact AAA at (614) 431-3388 and have the vehicle towed to NHTSA at 10820 SR 347 in East Liberty, OH in order for repairs to be made. If the vehicle becomes undrivable *outside of normal business hours*, simply contact AAA at (614) 431-3388 and have the vehicle towed to NHTSA for repair.



**Collision:** If the vehicle is involved in any type of **minor collision** and sustains *little or no damage (even a minor “fender bender”)*, you must use the mobile phone located in the vehicle's trunk to notify the Principal Investigator of this condition and make arrangements for the vehicle to be temporarily returned to NHTSA to ensure that all instrumentation is functioning properly.

If the vehicle is involved in a more **severe collision** and sustains damage and/or is **undrivable**, you must use the mobile phone located in the vehicle's trunk to notify the Principal Investigator of this condition and then contact AAA at (614) 431-3388 and have the vehicle towed to NHTSA at 10820 SR 347 in East Liberty, OH in order for repairs to be made.

You should not under any circumstances take the vehicle to any commercial automotive maintenance facility to be serviced without prior consent of the Principal Investigator. All repairs shall be performed by NHTSA or at their discretion. Upon repair, the vehicle will be returned to you as soon as possible to continue participation in the study.

**Study Completion:** At the end of the two-month period, you will be asked to complete a questionnaire asking your opinions regarding such issues as driving automobiles, trends in new vehicle design, and your experience in this data collection effort. Your assistance will help NHTSA understand the relationship between driver behavior and automotive safety. If you agree to participate, you will be asked to sign the attached Informed Consent Form indicating that you have read and understand the procedures of this study.

**Return of the Research Vehicle:** At the end of the two-month period, you will be required to return the research vehicle to NHTSA. The anticipated return date for you to return the research vehicle to NHTSA is: \_\_\_\_\_.

**Compensation:** Your participation should take approximately two months and your compensation will be \$200. Please note that additional compensation will not be provided in the event that the test lasts longer than two months. I understand that if I engage in illegal activities during my use of the vehicle or fail to meet the minimum “Driving Requirements” as outlined in this Information Summary I may be disqualified from the study and may forfeit my eligibility to receive the payment of \$200.

**Use of Information Collected:** In the course of this study certain **engineering data** and video recorded image data, or **videotape data**, will be collected.

The **engineering data** collected and recorded in this study will be analyzed along with data gathered from other test participants. NHTSA may publicly release this data in final reports or other publications or media for educational, outreach, and research purposes. However, your name and other personal identifying information will not be included in any of these public releases.

The **videotape data** collected and recorded in this study includes your videotaped likeness. NHTSA may publicly release this videotape data (in continuous video or still formats), either separately or in association with the appropriate engineering data. However, your name and other personal identifying information (except your videotaped likeness) will not be included in any of these public releases.

Please note that, should you be involved in a crash or other event during testing which results in legal action, NHTSA may be required to release personal identifying information and associated test data, in response to a court action.

**Informed Consent:** By signing the **informed consent** statement contained in this document, you agree that participation is voluntary and you understand and accept all terms of this agreement. Also by signing the informed consent statement, you agree to the following conditions of participation regarding operation of the research vehicle:

- a. I will drive the instrumented research vehicle provided to me by NHTSA to and from work at least four days per week for a period of two months as specified by the Principal Investigator. I understand that if any circumstances would affect my ability to meet the minimum "Driving Requirements" as outlined in this Information Summary, I must notify the Principal Investigator immediately.
- b. You, the participant, are the only person permitted to drive the research vehicle. The participant is defined as the one individual who agreed to participate in this study and signed the informed consent form.
- c. The research vehicle can not be used to tow any form of trailer, or haul any material greater than what the vehicle was designed to accommodate.
- d. You may not remove, modify, tamper with, or otherwise hinder the operation of any components of the research vehicle or data collection system or allow others to do so. You must receive verbal permission from the experimenters prior to allowing any mechanical work to be performed on the research vehicle.
- e. The research vehicle can not be used to conduct illegal activities.
- f. You must agree to operate the research vehicle in accordance with all traffic laws.
- g. You cannot drive the research vehicle while impaired by alcohol or any controlled substances. You will not permit others to consume alcohol or use drugs or other controlled substances inside the research vehicle.
- h. You are the sole individual responsible for your conduct while driving the research vehicle.
- i. You are responsible for purchasing fuel for the research vehicle for the duration which it is assigned to you.
- j. The research vehicle can not be taken outside of the state of Ohio.
- k. You are the sole individual responsible for all tickets and violations for the duration which the research vehicle is assigned to you.
- l. You are responsible for reporting as early as possible to NHTSA any problems, mechanical malfunctions, or collisions involving the research vehicle.
- m. If at any time, and for any reason, the experimenters deem it necessary that the research vehicle be returned to NHTSA, you must either return the vehicle or make it available for NHTSA personnel to retrieve it.
- n. You must return the research vehicle at the specified date and time your assignment ends as specified by the Principal Investigator.

You may withdraw your consent and discontinue participation at any time without penalty or loss of benefits to which you are entitled.

**Disposition of Informed Consent:** NHTSA will retain a signed copy of this Informed Consent form. A copy of this form will also be provided to you at the time you receive the research vehicle for commencement of your participation in this study. A copy of this form will also be present in the research vehicle at all times so that you will have access to contact information in order to reach the Principal Investigator in the event that you have questions or vehicle problems.

**Information Disclosure:** By signing the **information disclosure** statement contained in this document, you agree that NHTSA and its authorized contractors and agents will have the right to use the engineering data and the videotape data for educational, outreach, and research purposes, in perpetuity, including dissemination or publication of your likeness in videotape or still photo format, but that neither NHTSA nor its authorized contractors or agents shall release your name or other personal identifying information; and you understand that, in the event of court action, NHTSA may not be able to prevent release of your name or other personal identifying information.

#### **INFORMED CONSENT STATEMENT:**

I certify that all personal and vehicle information as well as information regarding my normal daily driving habits provided by me to NHTSA and TRC employees associated with this project during the pre-participation phone interview and the introductory briefing was true and accurate to the best of my knowledge. I understand that if I engage in illegal activities during my use of the vehicle or fail to meet the minimum "Driving Requirements" as outlined in this Information Summary I may be disqualified from the study and may forfeit my eligibility to receive the payment of \$200.

I understand that the purpose of this study is to assess the performance of a state-of-the-art automotive data acquisition system used to collect data on how people drive.

I, \_\_\_\_\_, VOLUNTARILY CONSENT TO PARTICIPATE.

I UNDERSTAND THE TERMS OF THIS AGREEMENT AND AGREE TO THE FOLLOWING CONDITIONS:

1. I will drive the instrumented research vehicle provided to me by NHTSA to and from work at least four days per week for a period of two months as specified by the Principal Investigator. If I experience a job change which results in my daily one-way commute being less than 45 miles in length or containing less than 30 miles of roadway having a speed limit of 55 mph or greater, I will notify the Principal Investigator immediately. I will notify the Principal Investigator if any changes in my work hours occur to ensure that data may be collected properly.
2. I, the participant, am the only person permitted to drive the research vehicle. The participant is defined as the one individual who agreed to participate in this study and signed the informed consent form.
3. The research vehicle can not be used to tow any form of trailer, or haul any material greater than what the vehicle was designed to accommodate.
4. I will not, or allow others to, remove, modify, tamper with, or otherwise hinder the operation of any components of the research vehicle or data collection system. I must receive verbal permission from the Principal Investigator prior to allowing any mechanical work to be performed on the research vehicle.
5. The research vehicle can not be used to conduct illegal activities.
6. The research vehicle can not be driven or otherwise taken outside of the state of Ohio.

7. I will not drive the research vehicle “off road”, or on any form of test or race track, nor will I use the vehicle in the performance of any stunt.
8. I agree to operate the research vehicle in accordance with all traffic laws.
9. I will not drive the research vehicle while impaired by alcohol or any controlled substances. I will not, or allow others to, consume alcohol or consume or possess other controlled substances inside the research vehicle.
10. I am the sole individual responsible for his/her conduct while driving the research vehicle.
11. I am responsible for purchasing the 89 Octane fuel necessary for operation of the research vehicle for the duration which it is assigned to me.
12. I am the sole individual responsible for all tickets and violations for the duration which the research vehicle is assigned to me.
13. I am responsible for reporting as early as possible to NHTSA any problems, mechanical malfunctions, or collisions involving the research vehicle.
14. If at any time, and for any reason, the Principal Investigator deems it necessary that the research vehicle be returned to NHTSA, I must either return the vehicle or make it available for NHTSA personnel to retrieve it.
15. I must return the research vehicle at the specified date and time my assignment ends as specified by the Principal Investigator and as indicated in this document.
16. I will familiarize myself with the characteristics of the research vehicle, its safety features, and the location of frequently used controls prior to driving the research vehicle for the first time.
17. I understand that the vehicle that I will be driving is equipped with the following features:

VEHICLE FEATURE	"X" IF PRESENT ON THIS VEHICLE
Power Door Locks	
Automatic Door Locks	
Remote Keyless Entry	
Vehicle Theft Security System	
Power Windows	
Remote Trunk Lid Release	
Automatic Temperature Control	
Automatic Dimming Center-Mounted Rear-View Mirror	
Manual Seat Adjustment	
Power Seat Adjustment	
Electronic Speed (Cruise) Control	
Power Brake System	
Antilock Brake System	
Power Assisted Steering	
Speed Proportional Steering	
Traction Control System	
Manual Lap Belt	
Manual Shoulder Belt	
Automatic Shoulder Belt	
Daytime Running Lights	
Driver's Side Air Bag	
Passenger's Side Air Bag	

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Signature

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Date

**INFORMATION DISCLOSURE STATEMENT:**

I, \_\_\_\_\_, grant permission, in perpetuity, to the National Highway Traffic Safety Administration (NHTSA) to use, publish, or otherwise disseminate engineering data and videotape data (including continuous video and still photo formats derived from the video recording) collected about me in this study for educational, outreach, and research purposes. I understand that such use may involve widespread distribution to the public and may involve dissemination of my likeness in videotape or still photo formats, but will not result in release of my name or other identifying personal information by NHTSA or its authorized contractors or agents. I understand, however, that in case of a crash or other event resulting in legal action, NHTSA may be required by subpoena or other court action to release identifying personal information.

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

## QUESTIONNAIRE

DATE: \_\_\_\_\_ SUBJECT #: \_\_\_\_\_

1) What is your birth date?           /          /            
Month / Day / Year

- ' Primary School
- ' High School Diploma
- ' Technical School
- ' Associates Degree
- ' Some Undergraduate School
- ' Bachelors Degree
- ' Some Graduate or Professional School
- ' Graduate or Professional Degree

- ' Under 2,000  
' 2,000 - 7,999  
' 8,000 - 12,999  
' 13,000 - 19,999  
' 20,000 or more

- ' Yes  
' No (skip to question 9)

- ' Under 2,000  
' 2,000 - 7,999  
' 8,000 - 12,999  
' 13,000 - 19,999  
' 20,000 or more

- 54

**35mph:** \_\_\_\_\_

**45mph:** \_\_\_\_\_

**55mph:** \_\_\_\_\_

**65mph:** \_\_\_\_\_

7) What type of automobile do you drive most often?

Make (e.g. Ford, Toyota)

Model (e.g. Escort, Celica)

Year

8) Which of the following features does your automobile have? (Check all that apply)

- ' Air Bag
- ' Antilock Brakes
- ' Automatic Transmission
- ' CB Radio
- ' Cellular Phone
- ' Manual Transmission
- ' Power Brakes
- ' Power Steering
- ' Radar Detector
- ' Other technologies (e.g. trip computer, moving-map display). Please list these here:
- ' None of these



## OPINIONS OF VEHICLE / FEATURES

The following questions deal with your opinions about the vehicle which you were given to drive in this study. Circle the number corresponding to the most appropriate response:

1) What is your opinion of the seatbelt design?

1	2	3	4	5
Very Unsatisfied	Somewhat Unsatisfied	Neutral	Somewhat Satisfied	Very Satisfied

2) Do you have any suggestions for improvement of the seatbelt design?

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3) What is your opinion of the adequacy of the supplemental restraint system in the vehicle?

1	2	3	4	5
Very Unsatisfied	Somewhat Unsatisfied	Neutral	Somewhat Satisfied	Very Satisfied

4) Do you have any suggestions for improvement of the supplemental restraint system?

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5) What is your opinion of the adequacy of the control / display systems layout and design?

1	2	3	4	5
Very Unsatisfied	Somewhat Unsatisfied	Neutral	Somewhat Satisfied	Very Satisfied

6) Do you have any suggestions for improvement of the control / display systems layout and design?

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7) What is your opinion of the adequacy of the vehicle's handling / maneuverability capabilities?

1	2	3	4	5
Very Unsatisfied	Somewhat Unsatisfied	Neutral	Somewhat Satisfied	Very Satisfied

8) Do you have any comments about the vehicle's handling performance?

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9) What is your opinion of the adequacy of the vehicle's braking performance?

1	2	3	4	5
Very Unsatisfied	Somewhat Unsatisfied	Neutral	Somewhat Satisfied	Very Satisfied

10) Do you have any comments about the vehicle's braking performance?

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11) What is your opinion of how comfortable the vehicle seemed to you?

1	2	3	4	5
Very Unsatisfied	Somewhat Unsatisfied	Neutral	Somewhat Satisfied	Very Satisfied

12) Do you have any suggestions for improvement to make the vehicle more comfortable?

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13) How did driving in the test vehicle compare to driving your vehicle?

1	2	3	4	5	6	7
Easier			Same			Harder

14) How did the vehicle's handling and braking performance compare to your personal vehicle?

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15) Would you consider purchasing a Chrysler Concorde for your own personal vehicle?

- ' Yes
- ' No

16) Any other comments about the vehicle which you were asked to drive?

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Thanks again for your participation!

COMMENTS:

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